The Air Pollution Implications of the Residential Sector: Case Study of the Mexico City Metropolitan Area

by

Kellyn E. Roth

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Signature of Author______________________________
Technology and Policy Program, Engineering Systems Division
Department of Urban Studies and Planning
January 17, 2003

Certified by______________________________
Mario J. Molina
Institute Professor
Thesis Supervisor

Certified by______________________________
Diane E. Davis
Associate Professor Of Sociology
Thesis Supervisor

Certified by______________________________
Stephen R. Connors
Director, Analysis Group for Regional Electricity Alternatives
Thesis Supervisor

Accepted by______________________________
Daniel E. Hastings
Director, Technology and Policy Program
Chairman, Committee for Graduate Students

Accepted by______________________________
Dennis M. Frenchman
Professor of the Practice of Urban Design
Chair, MCP Program

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ABSTRACT

The residential sector has been a long-acknowledged, but seldom-addressed, source of air pollution in the Mexico City Metropolitan Area (MCMA). The combination of high emission levels and large numbers of people directly exposed means that the indoor environment is a unique situation. If current trends of demographic growth, urbanization and increased appliance saturation continue, the urgency to address residential sector emissions will increase considerably. Additionally, households have wide-reaching impacts on many sectors including industry through the demand for appliances, power generation and fuel suppliers through the demand for energy, services through the demand for infrastructure, and many more.

Through recent efforts, researchers at MIT and in Mexico have attempted to understand and represent the residential sector, to identify and mitigate emissions release and exposure, most of which is energy-related. To reduce energy consumption, and thus emissions, in the home several strategies have been considered: reduced and improved use of fuel; increased energy efficiency; fuel leakage prevention and improved practices; improved building efficiency; and improved fuel transmission and delivery. Another issue of concern in this sector is the use of toxic solvents.

Household air pollution reduction strategy outcomes are difficult to predict because of the diversity of households (e.g., size, income, location) within the residential sector. Determination of the factors that affect energy consumption and household behavior would be very useful to decision makers as they develop more targeted policies for the provision of energy services and reduction of household-generated emissions.

Thesis Supervisor: Mario J. Molina
Title: Institute Professor

Thesis Supervisor: Diane E. Davis
Title: Associate Professor Of Sociology

Thesis Supervisor: Stephen R. Connors
Title: Director, Analysis Group for Regional Electricity Alternatives

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CHAPTER 1. INTRODUCTION

The Mexico City Metropolitan Area (here after referred to as MCMA, Mexico City or Metropolitan Area) is the second largest metropolitan area in the world with over 18 million inhabitants (the largest is Tokyo, Japan with 26 million people), roughly one-fifth of Mexico's entire population. The MCMA produces more than a third of the national GDP and generates, in the process, five million tonnes of atmospheric pollutants and four million tonnes of waste per year. Growth in the MCMA has led to an increase in regional air pollution and concern about the implications for human health. This first chapter will further introduce the problem of air pollution in the MCMA, describe a program at the Massachusetts Institute of Technology (MIT) initiated to assist the local government in dealing with this problem, and explain how the residential sector of the MCMA contributes to this problem.

Mexico City Air Pollution

Currently, Mexico City is the second most polluted city in the world in terms of air pollution (World Bank, 2001), a drop from the number one position it held about a decade ago, and the UN has indicated that the air pollution in Mexico City is one of the worst among all megacities (UNEP/WHO, 1993). Virtually all air pollutants – traditional air pollutants as well as toxic and carcinogenic chemicals – can be found in the city's air, affecting the health, visibility and environment of its residents. The air pollution problem could not be denied after reports of bird and plant death and high human mortality during the eighties.

The Metropolitan Area's topography and geography is conducive to developing and maintaining local air pollution. The areas high elevation results in less efficient fuel combustion and higher pollutant emissions. The air pollution situation is further exacerbated because the entire area is surrounded by various mountain ranges that function as a natural barrier, trapping gases and particulate matter. Winds rarely blow with enough force to clear the city's air from the valley.

In the beginning of the 1990's, air quality standards regarding all criteria pollutants were exceeded almost every day. After two decades of effort by local and federal governments, improvements in air quality have occurred but have failed to significantly decrease the overall level of all criteria air pollutants. Ozone values still violate air quality standards eighty-five percent of the days. Maximum peaks of particulate matter (PM) now reach 1.5 times the standard and violations occur on about 30 percent of days of the year (Molina, 2000).

However, the *rate* of increase of air pollution has been reduced from its previous state. A strong management focus has been taken since 1990, with leadership by the Federal District Government (DDF), integrating national government institutions, the State of Mexico Government, as well as the state-owned oil industry and numerous private actors. Citizens have also been motivated by government programs to improve their environment (e.g., by planting trees under the Cada Familia un Arbol, Urban Reforestation Programs).

Improvements have been achieved in some of the most critical parameters for air quality. Examples include dramatic reductions in lead concentration and in emissions of carbon monoxide (CO). Sulfur dioxide (SO_2) pollution has also been reduced in sufficient amounts to reduce, or eliminate, unhealthy levels in the MCMA. Current ozone and particulate matter (PM10) concentration peaks are at levels less than half of those registered during 1991 (Molina, 2000). High levels do, however, still occur; on September 18, 2002 the MCMA experienced its first air pollution contingency in three years, due to high ozone levels.

Continued population and industrial growth and limited enforcement of existing environmental protection regulations have contributed to the mixed success of governmental policies for pollution mitigation. With an increase in national GDP, and the country shift towards "modern consumerism," people are moving further away from the city center and towards required personalized transport and increased vehicle and household fuel consumption.

These trends, and many others highlighted below, contribute to severe effects, both financial and health related. A recent study by the World Resources Institute suggests "The [air] pollution in Mexico City is among the world's worst for young children" (WRI, 2002). While infant mortality in Mexico was at an average of 35.5 infant dealths per 1,000 live births in 1999, infant mortality in the MCMA was estimated at 46.6 in the same year. According to the World Health Organization, the average level of particulate matter in the city exceeds international standards by a factor of two. In 1999, ozone levels exceeded international standards for 212 days during the year. Air pollution-induced mortality was estimated to be 4,520 people annually in 1999. Thousands of Mexico City residents, especially children suffer from migraine, asthma and other respiratory problems (WHO, 1999). According to the World Bank, air pollution in Mexico City has reduced the national GDP by nearly six percent (WB, 1997).

The Mexico City Program

The most recent air pollution mitigation effort, the Program to Improve Air Quality in the Valley of Mexico 1995-2000 (PROAIRE), has recently come to an end. Members of the Metropolitan Environmental Commission (CAM) have developed a new air quality program, PROAIRE 2002-2010, for the MCMA to be implemented in the upcoming years. The plan has short-, medium-, and long-term goals for air quality in the region. CAM and other Mexican government organizations have requested assistance from a research program at Massachusetts Institute of Technology (MIT) – the Alliance for Global Sustainability (AGS) – to help develop this program and decision-making tools to implement these goals.

The magnitude and complexity of the atmospheric pollution, and resulting health problems in the MCMA, requires a multidisciplinary approach with solid scientific and technical foundation and an integrated strategy for decision-making. CAM, in collaboration with the MIT team, prepared a proposal entitled "Program for the Design of an Integrated Strategy for Air Quality Management in the Mexico City Valley 2001-2010," which was submitted to the Valley of Mexico Environmental Trust-fund and approved. The resulting Integrated Program on Urban, Regional and Global Air Pollution: Mexico City Case Study (Mexico City Program) at MIT is analyzing inter-sectoral strategies for the reduction and management of air pollution in the MCMA. The Program seeks to build the capacity of Mexico City and other developing nation megacities to address such problems by considering the effects of pollution on human health, the economy, ecosystems as well as international problems such as global warming. The approach will inform the Federal District, State of Mexico, National Government and other interested parties and stakeholders about which emissions to target first and what policy options may be the most effective for reducing those emissions at a reasonable cost.

The Residential Sector

The main focus of this thesis is air pollution from one sector analyzed within this Program – the residential sector. I focus on technological, demographic, economic and environmental influences to emissions from this sector, which contributes the air pollution problems described above. I believe that my approach, and the Integrated Scenario Tradeoff Analysis, expands the knowledge base of residential urbanization processes and can be used as a foundation for comparative studies and decision-making and policy development in other megacities, especially in Latin America.

The residential sector, as defined by this Program, includes all households within the MCMA. To understand the intricacies of this sector a profile including existing technology and energy options, penetration of appliance types, turnover rates and socioeconomic factors such as urbanization, household size, income distribution and housing tenure (degree of home ownership) must be identified. There are approximately 4.5 million households in the MCMA and this number is increasing. In 1996, the residential sector of the MCMA consumed approximately one-fourth of the total energy in the MCMA. Residential fuel consumption, along with the storage, transportation and distribution of these fuels as well as solvent use, comprises the most significant source of indoor air pollution and exposure. As current trends continue, these patterns must be addressed.

The residential sector provides the opportunity to evaluate the implications of household energy and resource consumption and other decisions that affect their indoor environment and personal exposure, as well as metropolitan, regional and global air quality. The importance of the MCMA in Mexico's urban population makes this study an important tool for developing policies to promote informed energy consumption decisions and energy efficiency in residential households as well as for energy sector planning.

The following Chapter of this document outlines the primary research objectives and methodology used for the Program and evaluation of the residential sector. It also provides justification for the Program and intended application of results.

Next, a more detailed description of Mexico City, as it relates to air pollution, is provided in Chapter 3. Physical characteristics are described as well as pollution sources, trends and effects.

Chapter 4 then provides more detail on Mexico City's residential sector. This section examines current conditions and spatial and temporal trends of household characteristics such as population, living conditions, household income and welfare and building structures. The key policies and regulations that effect residential air pollution, either by influencing household choices and behavior or by directly encouraging household pollution generation reduction, are also described

Based on this information about Mexico City's residential sector, Chapter 5 describes its pollution sources and historical trends and preferences relating to this air pollution.

The next section, Chapter 6, describes a residential survey performed to gather information on household behavior and expected responses to pollution reduction policies.

Chapter 7 contains information on the analytical analysis behind this research Program. It describes the model used to estimate future trends of residential air pollution generation, under various control strategies and mitigation efforts.

Based on this qualitative and quantitative analysis, Chapters 8 and 9 summarize the findings of this research. Observations based on the model are provided as well as expected implications of policies. Additionally, this section suggests some of the barriers and key issues that will have to be overcome and/or considered before moving forward with residential sector air pollution reduction efforts.

CHAPTER 2. RESEARCH DESCRIPTION

Research Objectives

Air pollution produced by the MCMA residential sector will undeniably continue to increase and worsen unless action is taken. The population is expected to continue to grow; even if each person consumes far less than per capita consumption today, more total fuel combustion will occur. Urban sprawl is expected to continue, stretching the fuel delivery infrastructure and limiting consumers' fuel choice and availability. Income disparities can remain consistent or change dramatically, perhaps leading to an increase in overall income or a larger disparity between the wealthy and the low-income informal settlements. No matter what the future entails, it is important for decision makers to understand the residential sector and how it contributes to and interacts with air pollution drivers.

To justify this research, we must first ask, "How important is the residential sector?" Its emissions importance is relatively small in terms of the Emissions Inventory developed by CAM, which has been the basis of most Mexico City air quality management programs so far. However, once exposure assessments can accurately weigh indoor versus outdoor exposure, it may receive more attention. Also, when evaluating only the Emission Inventory and program costs, the residential sector may not present, at first glance, the most cost-effective strategies for the MCMA. Mexico City, relatively new in implementing pollution mitigation efforts, still has several "low hanging fruit." There are still so many large sources of emissions that can be dramatically reduced at relatively small costs. But, as exposure assessments are used, this effectiveness may shift benefits to indoor and direct exposure sources.

There are two types of air pollution exposure: ambient exposure from outdoor sources (e.g., power plants, automobiles and industrial emissions) and exposures from indoor sources (e.g., tobacco smoke, cooking, and use of household products). For many pollutants, such as benzene and particles, indoor sources may make more substantial contributions to personal exposure than outdoor sources (Molina, 2000)[1]. Additionally, because people spend much of their time indoors and because many pollutants can readily enter the indoor environment, much of the exposure from outdoor sources may actually occur indoors. Therefore, great improvements in public health are possible through programs and policies designed to encourage development of improved and less polluting household products, increase the energy efficiency of household appliances, switch to less polluting fuels and increase residential awareness of the issues.

The primary source of air pollution in the MCMA and from the residential sector is energy consumption. The Mexico City Program will try to determine what level of emissions reductions are desired and required in the Mexico City Valley, what changes in energy consumption and related practices will result in those reduction, and what policies will results in those changes. Evaluation at the residential/household level requires a

[1] Paulina Serrano, a participant in the work surrounding the Mexico City Program, has been performing empirical tests and analyzing evidence of such indoor exposure to household pollution sources.

large degree of specificity; households are very heterogeneous in terms of income, size, occupation, and other characteristics. This research will attempt to identify energy consumption factors – household characteristics that correlate to energy consumption behaviors and responses to external policies and influences. For example, given a ten percent increase in liquid petroleum gas (LPG) price, will households chose to switch to a different, less polluting fuel (ex – natural gas)? If so, which households? This analysis will lead to suggestions for policies and practices that promote and effect the desired changes in energy consumption and air pollution emissions.

Evaluating the costs of these emission reduction options will then enable the researcher, policy makers and other stakeholders to determine if there are benefits to addressing and attempting to reduce emissions. We can ask, since the contribution to the MCMA emission inventory is low, would it be more beneficial to reduce exposure and other health problems or reduce emissions levels? For example, "Would more lives be saved by providing running water to the about ten percent of households in the peripheral areas without it?" (Pick and Butler, 1997) These questions, beyond air pollution, are outside the scope of this thesis, but should be kept in mind when thinking about putting programs into practice.

Analyzing the residential sector also presents us with many other research questions that are beyond the scope of this thesis but for completeness, must be presented and considered. Based on Mexico City fuel and appliance emission factors, one of the largest residential sector emissions reductions seem to be possible through switching to less polluting fuels such as natural gas and electricity. However, switching to natural gas decreases some emissions but increases the risk of explosions, especially in an earthquake susceptible location such as Mexico City. The likely health risk of air pollution must be weighed against the less likely health risk of an explosion. There has not been much switching to electricity for major appliances such as cook stoves and water heaters because other fuels have historically and consistently been less expensive. Switching to electricity does not decrease overall pollution but moves it out of the valley, making it an attractive local option. If the research Program moves from a local pollution reduction goal to a regional one, this may no longer be desirable.

The remainder of this chapter describes the methodology used for the Mexico City Program, the Integrated Scenario Analysis of this Program and, specifically, the residential sector component. Justification is then provided for this Program and the residential sector focus.

Methodology

The Mexico City Program

The Mexico City Program (MCP) was initiated at MIT and involves the participation of an interdisciplinary group of researchers from Mexican academia, government and other institutions, as well as consultants from MIT and Harvard of the United States. The overall goal of the Mexico City Program is to improve the understanding of complex and important environmental problems, contributing to the improvement of the approach and methodologies used by developing nations, initially focusing on the Mexico City Metropolitan Area. The Program seeks to build the capacity of these nations to address such problems, by providing objective and balanced assessments of the causes and possible solutions to local, regional and global atmospheric pollution problems that are useful to decision makers. One of the primary challenges in the development of a coordinated, robust and cost-effective air quality management plan is to be able to address all of the relevant scientific, technical, political, economic and administrative aspects of the problem.

Integrated Scenario Assessment

The Mexico City Program has chosen to employ an integrated assessment (IA) approach to develop recommendations that facilitate the interaction between areas such as health, atmospheric science, economics, technology and policy. It considers effects of pollution on human health, the economy, ecosystems, as well as international problems such as global warming. The components of the IA are shown in Figure 1.

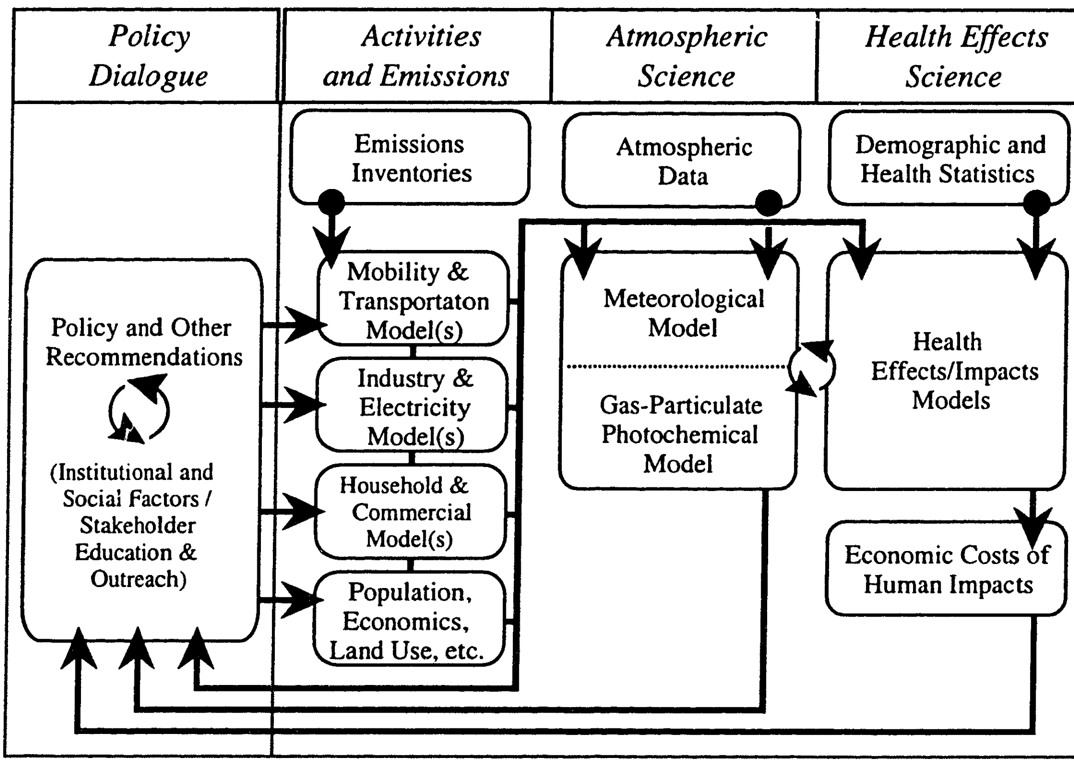


Figure 1. Mexico City Program Integrated Assessment Diagram.
Image designed and provided by Stephen Connors.

The MIT team is tasked with developing an Integrated Scenario Analysis for Mexico City, one that would Program air emissions, concentrations and resulting health impacts and monetary expenditures under various alternative conditions and policies. As in most developing countries, there is a limited supply of information; participants must also analyze associated uncertainties.

For each sector (transportation, industrial, commercial, residential, etc.), researchers will produce emissions and costs trajectories for the MCMA under various future scenarios and emissions control options. These costs and emissions can then be compared across all sectors and stakeholder impacts to identify optimal strategies for the government to implement.

The scenario analysis methodology has been institutionalized by Royal Dutch/Shell as a way to confront complex issues and future uncertainties. Scenarios, as defined by Shell, are coherent, credible stories about alternative futures and they help to create multiple perspectives to explore problems and possible development, options and actions. Shell has been using scenarios for the last thirty years to guide difficult decision-making.

Residential Sector Focus

As one student team member, I evaluated the residential sector – its sources of pollutant emissions, viable emissions reduction strategies, and feasibility of reduction alternatives and coordination of these alternatives with other sector approaches. This evaluation was accomplished by collecting information through a literature review, interviews and collaboration with Mexican policy makers and stakeholders, a household survey, and the development of a bottom-up model.

Literature Review

The first step was to perform a broad literature search and review. A comprehensive literature review was undertaken to find information on four broad topics: (1) the residential sector and its contribution to local, regional and global air pollution; (2) patterns of household energy use (especially in developing countries), recent research on energy behavior (by households) and energy consumption; (3) the effect of household energy consumption on indoor air pollution and occupant health; and (4) relevant national and local environmental policies. The literature search was performed using several social science, energy, urban planning and environmental databases and included contributed reports and articles from Program participants and collaborators.

Interviews/collaboration with government

Researchers on this Program are fortunate because of the direct collaboration and assistance available from Mexican government officials and employees. These collaborators provided much of the data and information used in this Program. Sources of data included government census and surveys, fuel information from Pemex and other fuel distributors, and research data from Mexican universities and governmental institutions. Additional intuition was supplied and developed through continued contact and conversations with these individuals and other Mexico City residents introduced to us.

Survey

Several domestic residential energy surveys have been performed in other urban developing areas, but none in Mexico City and few in Mexico. By assessing the relevant literature, the methodology of prior surveys and the goals of the Mexico City Program, it was decided that a survey should be performed in the MCMA to determine current household conditions such as fuel and appliances choices and expenditures and household energy consumption indicators such as occupant characteristics, attitudes and actions, and other characteristics. In addition to this information, the survey was used to identify key drivers in energy consumption and other household decisions and educate household members on their implications. This information is essential before making household energy policy (Sheinbaum, Martinez & Rodriguez, 1996; Barnes & Floor, 1996) and was not available from other sources.

Identification of these drivers provides decision makers with improved information upon which to prioritize and implement effective air pollution reduction programs. It may also identify tensions between stakeholder goals (e.g., increased economic development through higher household incomes is likely to lead to more consumption and pollution). Through MIT and Mexican cooperation, emissions reduction option implementation and the outreach portion of the survey, the air pollution produced in the residential sector could be reduced, providing an example for other areas.

Model

The information gathered through the literature review and data collection and enhanced by the survey has been used to model the residential sector individually and as part of the Program's Integrated Scenario Analysis to estimate future household behavior, including energy consumption and resulting air emission and cost impacts under several policy options and predictions of future economies, growth patterns and political structures. Other Program team members then converted this emissions information into atmospheric pollutant concentrations and health effects.

A bottom-up approach was used to model the residential sector: sources of pollutant emissions; viable emissions reduction strategies; technological, economic, and political feasibility of reduction alternatives; and coordination of these alternatives with other sector approaches. Options being considered include switching to alternative fuels, improving appliance efficiency and fuel leakage reduction. Air pollution reduction strategies must be robust across varied future possibilities characterized by local, regional and global factors.

Justification

One of the major problems the Mexico City government has experienced when designing environmental regulation has been a lack of historical information. The Mexico City Program team will collect, consolidate and evaluate many sources of information into one coherent source.

Many of the data sources used during development of the residential model did not provide consistent and long-term historical data. Additionally, data was often incomplete and excluded irregular housing settlements or defined the MCMA in a way different from the Program.

As mentioned earlier, energy surveys performed in other areas were consulted for information relevant for Mexico City. Few of these energy surveys, however, have been in urban areas in developing regions. One study in Mexico (Masera & Navia, 1996) surveyed households in rural villages to examine fuel wood use and fuel switching patterns. While the relationship between household characteristics and energy consumption behavior may have been researched in other settings, MCMA decision-makers need to understand the situation in Mexico City. The situation there is unique in terms of income distribution, population growth, energy pricing policies and supply and other factors.

The majority of the household energy surveys were designed to measure household energy consumption response to external information and not to gauge current practices and potential responses to various future situations. Many of the households surveyed over extended periods of time volunteered for the program, creating self-selection bias. Additionally, most identified household characteristics did not indicate occupant attitudes and how these households would respond to government policies.

There exists an opportunity to narrow the literature gaps and contribute to the body of knowledge on household energy consumption. It is important to understand what influences households to make their fuel choice and consumption decisions. Perhaps socioeconomic household characteristics are appropriate indicators of energy consumption behavior, but these indicators may change or shift over time. Additionally, we can try to determine what types of policies will be most effective *in the MCMA* in improving residential air quality. The survey portion of this research will attempt to measure household characteristics and occupant behavior that influence energy consumption, and will then predict how this knowledge can be used to reduce energy consumption. Like the referenced surveys, precise quantification is difficult because the number of households, or energy consumers, is so large. This survey will serve as a small-scale test of the questionnaire's usefulness.

I hypothesize that household income, housing tenure (level of ownership) and availability of services are the dominant MCMA characteristics that affect ability and desire to make energy consumption changes. Consumers, particularly those in Mexico City where fuel and appliance choices and disposable income are limited, have a general lack of knowledge about the fundamental differences between and impacts of their energy choices–delivery methods, advantages and disadvantages and methods for better energy consumption management.

For the residential sector specifically, much of the information gathered through this survey will be different than what is already collected by the government, including energy expenditures, appliance turnover and household environmental awareness. The Program team and the Mexican government can use the survey instrument to gather periodic information on energy consumption in order to verify modeling and policy assumptions and to determine long-term trends. Quantitative household data could also be gathered to determine annual, monthly and seasonal variation[2]. Planning departments of housing agencies, fuel suppliers, appliance manufacturers and other parties could then use the data to better assess the market and anticipate and provide household needs.

The Integrated Scenario Analysis can be used as a tool for decision-makers to develop policies that can promote reduced air emissions and overall sustainability in the MCMA through efficient policies. Because this information has been specifically requested by our Mexican government partners to be used for future policy development, it is important to provide information specific to the MCMA and not extrapolate or estimate based on prior, far-removed surveys and research.

[2] The average energy consumption norm does vary significantly for cooking and water heating in various seasons (Ramachandra, 1999).

CHAPTER 3. MEXICO CITY PROFILE

The purpose of this chapter is to introduce the Mexico City Metropolitan Area (MCMA). First, the physical attributes are described including presentation of recent trends in population, size and importance to surrounding areas and Mexico. Then, more information is provided on the current environmental conditions, more specifically air pollution, of the area. Sources of air pollution, type of pollutants, and efforts to monitor and regulate this growing problem are outlined.

Mexico and Mexico City Characteristics

The MCMA is one of the largest urban areas in the world. The United Nations defines a megacity as an urban population that was over 8 million in 2000; the World Bank increases this threshold to 10 million inhabitants. The MCMA meets either definition. The combination of high population density, poverty, and limited resources in the MCMA and other megacities intensifies conditions of disease, infrastructure deficits, environmental problems, external economic dependence and capital scarcity (Bugliarello, 1999).

The MCMA is situated in the Mexican Basin in central Mexico at a mean altitude of 2,400 meters. The surrounding mountains have an elevation of over 5,000 meters. Two valley channels, located in the north-east and north-west, funnel the air to the center and the south-west portions of the city, but the mountains generally prevent wind circulation and pollution transport away from the central MCMA. Additionally, fuel burns less completely at high altitude, and frequent thermal inversions and high pressure systems mean that the surrounding mountains trap a layer of cold air above the city, preventing the dispersal of fumes.

The MCMA is composed of 16 delegations of the Federal District (DF), 40 municipalities of the State of Mexico (EM) and one municipality of Hidalgo, Tizayuca. Together, these regions have a surface area of 5,300 square kilometers (km^2), of which about 1,500 km^2 (~30 percent) is urban (Molina, 2002).

During the twentieth century, the area has changed dramatically. The population grew rapidly, continually occupying land further away from the historic center (Molina, 2000; Sheinbaum, Martinez & Rodriguez, 1996). In 2000, the population of the MCMA was over 18 million – over four million households (INEGI, 2000). Although the population growth rate is expected to decrease from the current 1.6 percent to about one percent per year in 2010, the population will continue to grow, passing 20 million inhabitants by 2010 and 22 million by the year 2020. The age distribution has also changed during this century; an increase in the elderly population, which doubled since 1995 (INEGI, 2000), indicates a growth in the group of the population sensitive to air pollution.

While approximately nine million people live in each the DF and the EM, the MCMA growth rate is not homogeneous – areas outside of the city center in the DF have a faster population growth (see Figure 2). A significant fraction of this expansion has occurred in irregular settlements; since poor sectors of the population do not have access to housing markets, they frequently settle illegally in vulnerable ecological zones, with low densities and infrequent service availability (Molina, 2000). It has been estimated that irregular settlements provide homes for sixty-two percent of the MCMA population and occupy almost fifty percent of the MCMA area (Molina, 2000). The total MCMA has a population density of about 3,000 persons per km^2, but the urban area population density ranges from greater than 18,000 persons per km^2 in portions of the city center to less than 1,000 persons per km^2 in outer, less populated zones (Gilat, 2002). The MCMA population density has decreased slightly over the years – the population is increasing at a slightly slower rate than the urban area. The MCMA is 98 percent urban by population, but only 32 percent urban by area (INEGI, 1995). In other words, almost the entire population of the MCMA is living in heavily populated areas. Figure 2 below shows the trend of increasing MCMA urban area.

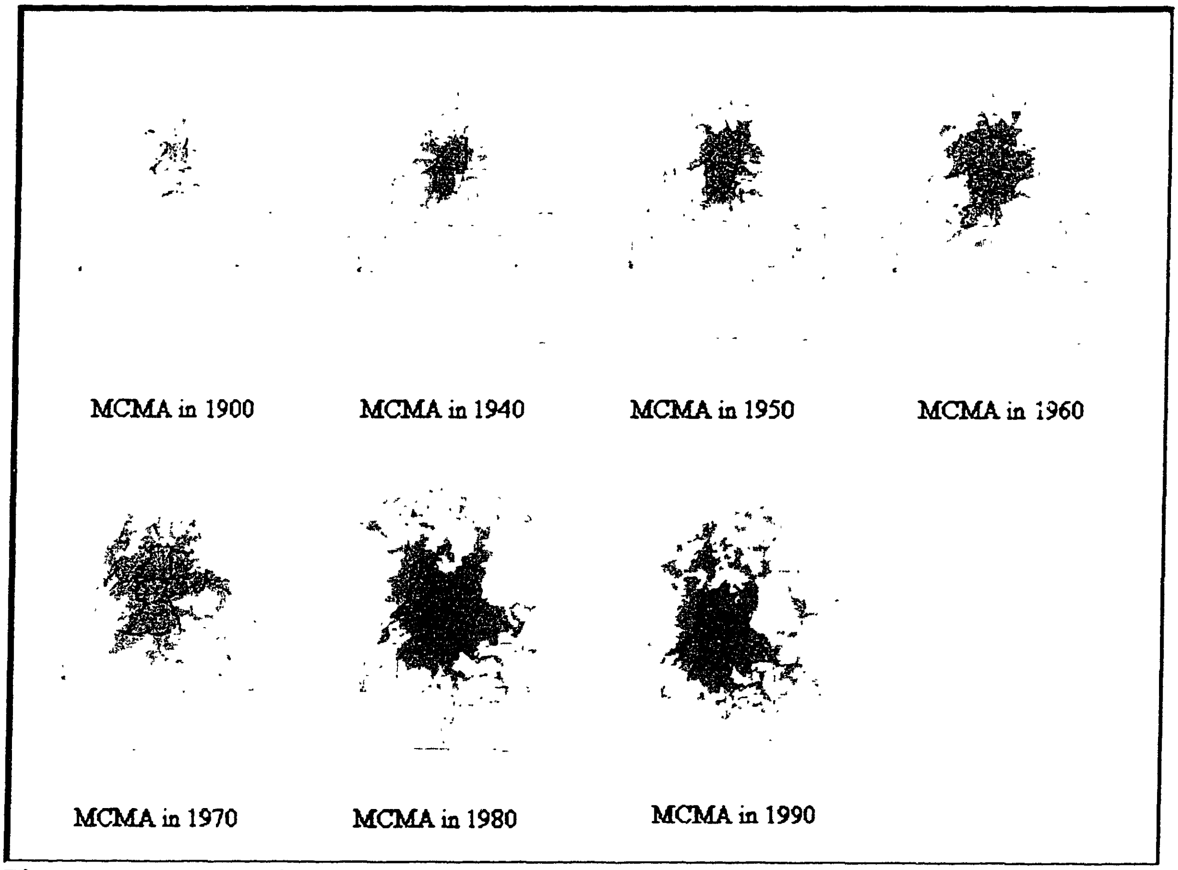
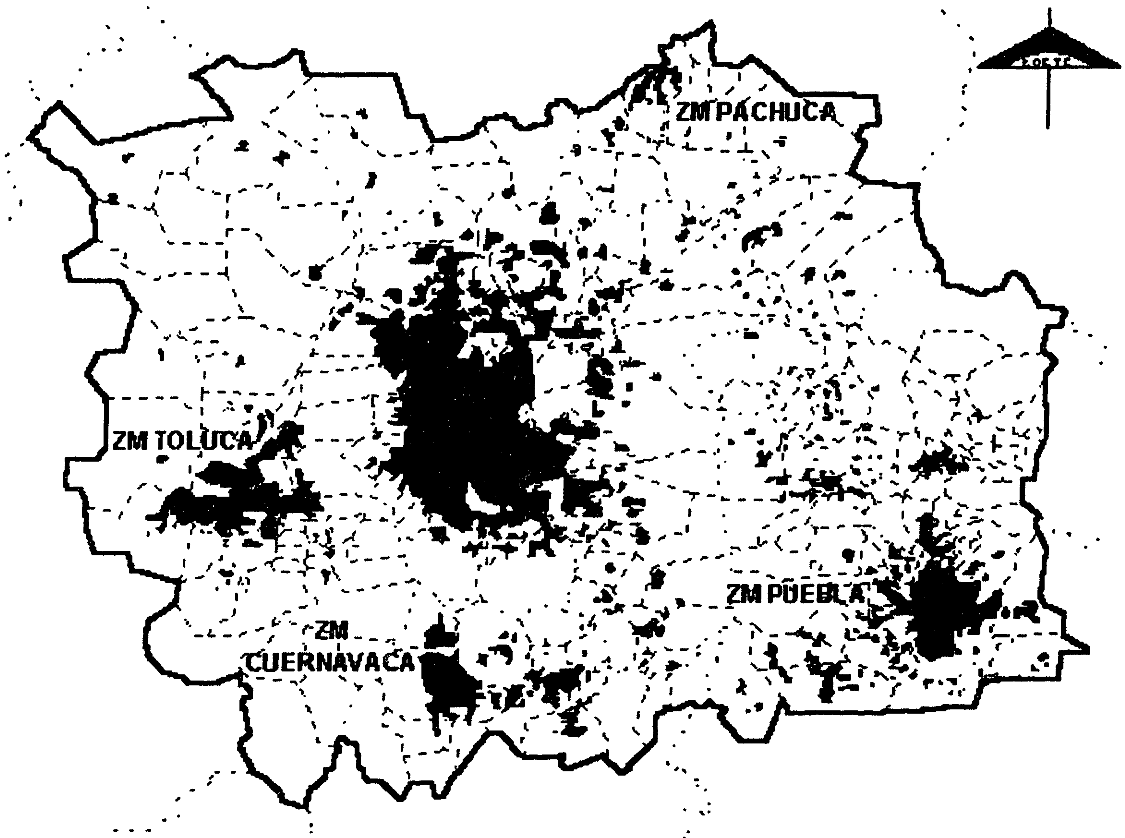


Figure 2. MCMA Urban Expansion 1900-1990 (Lemus, 1998)

Growth and land use patterns such as this are not unique in the region or the world. Neighboring metropolitan areas (Puebla, Tlaxcala, Pachuca, Toluca and Cuernavaca) are also extending their territories, as have other megacities (e.g., New York, Tokyo and Bombay) around the world. Within Mexico, the multiple expansion of these metropolitan areas forms a unique urban area that has been designated a megalopolis, as shown in Figure 3.

EL ESQUEMA DE PLANEACIÓN URBANO-REGIONAL DEL ÁREA DE ESTUDIO CONSIDERA ESTÁ DENTRO DE LA MEGALÓPOLIS.



La megalópolis comprende en total 189 municipios que se distribuyen así:

Distrito Federal	16
Estado de México	91
Estado de Puebla	29
Estado de Morelos	16
Estado de Tlaxcala	37
Estado de Hidalgo	16

Figure 3. Map of Mexico Megalopolis: Mexico City and Nearby Metropolitan Areas
Note: ZMCM = MCMA

Temperatures in the MCMA remain relatively constant throughout the year, with a monthly mean of 15 degrees Celsius (12° C in January and 17° C in May) (UNEP/WHO, 1993). Precipitation occurs primarily during the summer and totals about 725 millimeters per year. This precipitation pattern affects the concentration of pollutants such as suspended particulate matter by removing particles and soluble gases from the air. The geographic characteristics described above in conjunction with relatively light winds result in poor ventilation through the valley.

The MCMA contributes about one-third of the national Gross Domestic Product (GDP). There are more than 30,000 industries and over 12,000 service facilities in the MCMA (UNEP/WHO, 1993). All sectors of the MCMA consumed approximately 512 petajoules (PJ) of energy in 1986, and 570 PJ in 1998 (Bazan, 2000). These facts highlight the importance of the MCMA; its sustainability will undeniably affect the future of Mexico.

Air Pollution

The MCMA has a serious air pollution problem that has increased with the growth of the city size, population, industry and vehicular traffic. This section will present the primary sources of those pollutants, the monitoring and regulatory system established, ambient pollutant concentrations in the MCMA, distribution of pollutants and the key health effects of each.

Emissions and Sources

With the population growth and urban sprawl, the needs for fuel, housing, transportation, industrial production, services and natural resources grew, as did the generation of atmospheric pollutants. In combination with over 3.5 million vehicles and around 35,000 industries and commercial services, MCMA activities consume more than 44 million liters of fuel per day, producing thousands of tonnes of pollutant emissions. Many of these primary pollutants can react in the atmosphere to generate other, sometimes more dangerous, secondary pollutants. Figure 4 shows the recent 1998 Emissions Inventory prepared by CAM. The bars on the left show the total quantity of emissions and the bars to the right show the percentage contribution of each sector. Carbon Monoxide (CO) is only shown in the inset because its emissions are a relatively much greater magnitude.

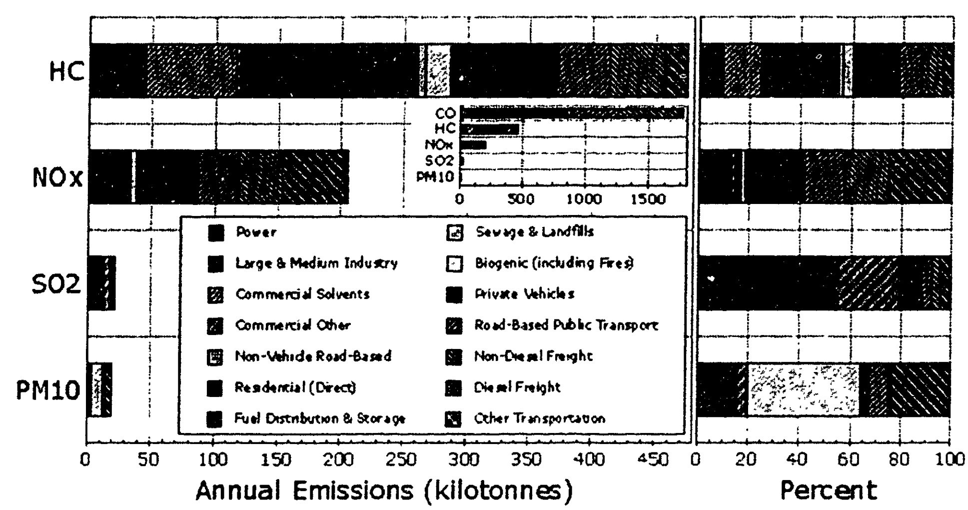


Figure 4. 1998 MCMA Emission Inventory (CAM, 2002)
Image designed and provided by Stephen Connors.

The scenario analysis methodology selected by the Mexico City Program will analyze emission sources on a sectoral basis. As shown, transportation sources dominate nitrogen oxides (NOx) and carbon monoxide (CO) emissions, but industry and other fuel combustions sources contribute. Industry and power plants are two of the primary sources of sulfur oxides (SOx). Particulate matter (PM) emissions results from fuel combustion as well as environmental degradation such as forest fires. Non-methane hydrocarbon (NMHC) emissions result from leakage of unburned fuel and use of solvents, as well as fuel combustion. Although not the primary emitter of any pollutant, residential sources do play a role in emissions of each.

CAM's estimation demonstrates the high levels of pollution in the MCMA and calls for concern and action to be taken. However, the situation may be even worse than is presented, for several emissions sources seem to have been excluded from the inventory including fuel wood consumption, informal commercial and residential activity, off-road vehicle use, and others.

Ozone, a product of volatile organic compounds (VOCs), including NMHCs, and NOx, is not included in this inventory because it is not a direct emission. Greenhouse gases, a global concern, are also excluded in this particular inventory, but one is available for the DF from another organization[3].

A main source of MCMA air pollution is energy consumption (UNEP/WHO, 1993). Figure 5 below shows 1998 non-electric energy consumption in the MCMA by fuel type. The consumption shown does not include final electricity consumption, but does include non-electric fuels consumed during the generation of electricity. Although some industries and residential and commercial structures have been switching from liquid petroleum gas (LPG) to natural gas since 1998, the percentages shown are still reasonable.

[3] This inventory could not be used for comparison with CAM's Inventory because different source and geographic categories are used.

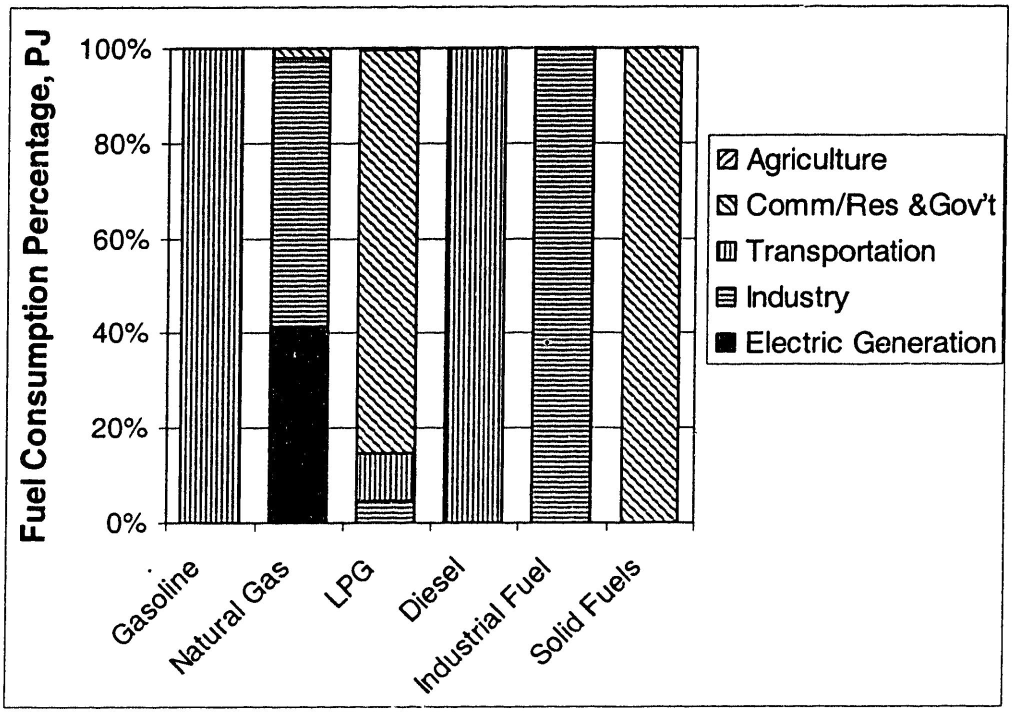


Figure 5. 1998 MCMA Non-electric Fuel Consumption, by Fuel (Bazan, 2000)

This figure illustrates the role of each sector for different fuels. The residential sector is the major consumer of LPG and solid fuels – primarily wood.

Figure 6 presents fuel consumption from the same year in a different format, to highlight the relative energy demand by sector. This figure can be used to determine quantities (PJ) of each fuel used.

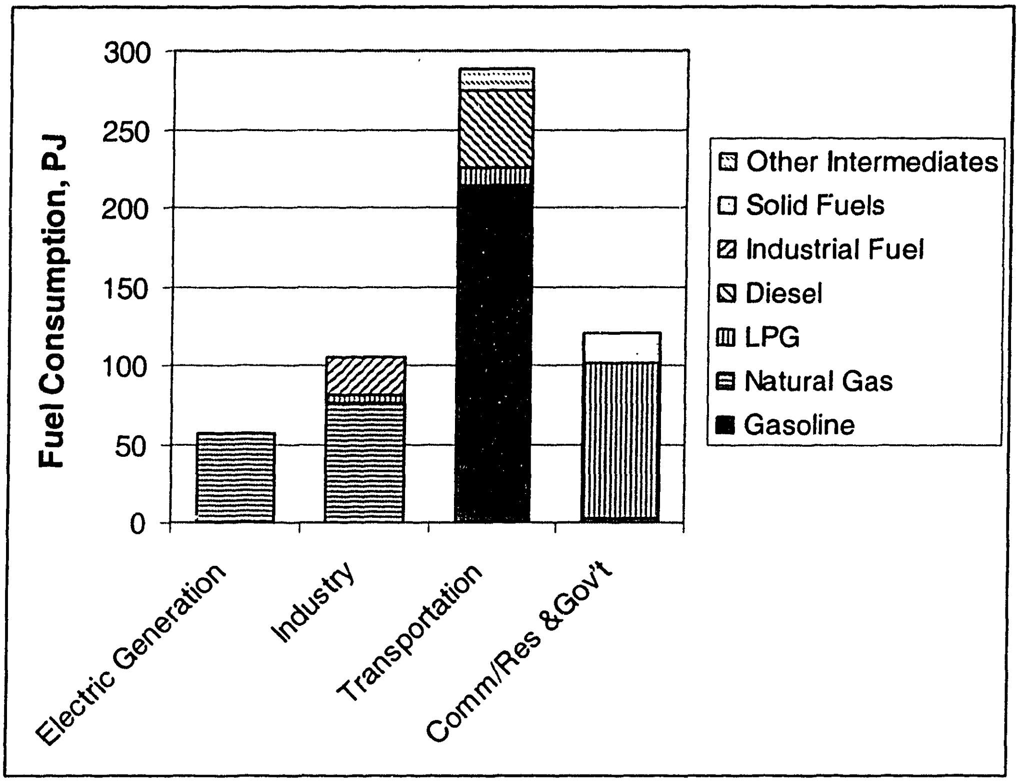


Figure 6. 1998 MCMA Non-electric Fuel Consumption, by Sector (Bazan, 2000)

The data shown in this figure does not include fuel consumed for agricultural purposes. Within Bazan's category of the commercial, residential and public sectors, the fuel most commonly used is LPG. And as we saw from Figure 6 above, most of this LPG is consumed in residential households. Electricity and wood consumption are also shown to be significant.

Monitoring

The Mexican government and citizens recognized air pollution as a problem and began monitoring pollutant concentrations in the 1950s. Initially, 14 monitoring stations were installed to monitor smoke, suspended particulate matter (SPM) and sulfur dioxide (SO_2). In the early 1970s, through support by the United Nations Environment Programme (UNEP), Mexican authorities developed a program to improve environmental quality in several cities. As part of this program, a manual network for SO_2 and SPM were installed and completed in 1976. In 1985, an automatic routine monitoring network was added through technical assistance by the U.S. Environmental Protection Agency (US EPA). The new network, titled Red Automatica (RAMA), measures SO_2, carbon monoxide (CO), ozone (O_3), nitrogen oxides (NOx) and non-methane hydrocarbons (NMHCs) and covers the majority of the MCMA. There are currently no routine measurements of VOCs in the MCMA, but measurements of some selected hydrocarbons are made at two sites. There are only five full capability stations, however, equipped to measure all of these five pollutants. One of these stations is located in each of the four city quadrants and in the city center. The 16 station manual network is still operational as well. Universities, such as the National (UNAM) and the Metropolitan (UAM), also use some of their own monitoring equipment.

Regulation

The measurements are reported daily to the public as an index value named an "IMECA" (Indice Metropolitano de la Calidad del Aire). The IMECA calculation scales each pollutant concentration from 0 (best) to 500 (worst) and sets the criterion value for each pollutant equal to 100 points. If the IMECA passes 300 points, a contingency program is triggered. This contingency program includes actions such as industry activity reductions and vehicle restrictions. Table 1 describes each IMECA Index level in terms of the health effects expected and the relative stringency compared to U.S. Environmental Protection Agency National Ambient Air Quality Standards (NAAQS), which are used to regulate metropolitan areas.

Table 1. Comparison of IMECA and U.S. EPA Ambient Air Quality Standards

Index	**IMECA description**	**U.S. NAAQS**
0-100	Satisfactory: Favorable environment for all types of physical activities.	Below NAAQS
101-200	Not Satisfactory/Bad: Slight reaction in predisposed persons.	Above NAAQS
201-300	Very Bad: Reaction and relative intolerance towards physical exercise in persons with breathing or cardiovascular problems. Slight reaction in the population in general.	Alert
301-400	Very Bad: Diverse symptoms and intolerance towards physical exercise in healthy people.	Warning
401-500	Very Bad: Diverse symptoms and intolerance towards physical exercise in healthy people.	Emergency
500+	Not described	Significant harm
Source: Ezcurra, 1999. The Basin of Mexico; SIMA, 2002; SMA, 2002		

For comparison, Tables 2 presents the numeric air quality standards for Mexico and the U.S. Environmental Protection Agency. As shown, the health-based standards are very similar.

Table 2. Comparison of Mexican and U.S. Health-based Ambient Air Quality Standards

Pollutant	Mexico		United States	
	Units	**Average**	**Units**	**Average**
O_3	0.11 ppm	1 hour	0.12 ppm	1 hour
SO_2	0.13 ppm 0.03 ppm	24 hours annual arithmetic mean	0.14 ppm 0.03 ppm	24 hours annual arithmetic mean
NO_2	0.21 ppm	1 hour	0.25 ppm 0.05 ppm;	1 hour annual arithmetic mean
CO	11 ppm	8 hours	9 ppm 35 ppm	8 hours 1 hour
TSP	260 g/m3 75 g/m3	24 hours annual geometric mean	Not Applicable	Not Applicable
PM10	150 g/m3 50 g/m3	24 hours annual arithmetic mean	150 g/m3 50 g/m3	24 hours annual arithmetic mean
Pb	1.5 g/m3	3 month arithmetic mean	1.5 g/m3	3 month arithmetic mean

ppm = parts per million
Source: EPA: US-Mexico Border XXI (2002); DuPont (1989)

Although studies of other metropolitan areas with urban pollution problems have been useful, each nation's air quality standards and laws to achieve reduction are, and should be, situation specific (LANL, 1999). While Mexican policies and actions have addressed a portion of the problem and reduced some emissions, serious problems still persist.

Distribution

Generally, air pollution as measured by RAMA is highly variable within the city with SO_2, O_3, and CO showing the greatest presence in all areas. SO_2 air quality standards are exceeded occasionally at specific sites (UNEP/WHO, 1993). Ozone levels are highest in the southwest and lowest in the northeast. Using information from Blake and Rowland (1995), it can be hypothesized that ozone produced from LPG leakage (during transmission, distribution and use, contributing to about 20 percent of ozone formation) would originate in the most populated sections and then be carried by the prevailing northeast winds to the southwest. As expected, CO levels peak during morning hours, when low temperatures and atmospheric inversions often occur in combination with high vehicular traffic.

PM is concentrated in the northeast and declined towards the southwest, possibly illustrating the importance of winds (Pick and Butler, 1997). PM emissions frequently violate daily and annual standards (Molina, 2000). PM10, particles less than 10 micrometers in size, have the most pronounced impact on health and visibility and typically represent between 40 and 60 percent of the total suspended particulate matter (SPM) reported by monitoring stations.

NOx concentration levels are often above WHO guidelines and the national air quality standards. During 1986-1991, safe levels of NOx were exceeded less than 5percent of the time (UNEP/WHO, 1993). NOx is also a precursor of ozone and, as expected, high NOx and HC pollutant levels and local topography and meteorological conditions contribute to very high ozone levels in the city. The greatest frequency of excess occurs in the south-western zone of the MCMA, at the Pedregal monitoring site. Eighty to 100 hours per month of exceedance is not unusual. .

Health Effects

The air pollutants present in the MCMA each have several health effects that have been associated with them. Table 3 presents the most common health effects and the primary pollutant sources.

Table 3. Common MCMA Air Pollutant Health Effects and Sources

Pollutant	**Primary Health Effects**	**Primary Sources**
NOx	Lung irritation, cardiovascular & respiratory effect, decrease in visibility, ozone formation	High temperature combustion in vehicles & industry Unvented appliances
CO	Alters nervous system, cardiac & pulmonary functions (headache, drowsiness, death)	Incomplete combustion of fuels and fire Solid fuel combustion Unvented appliances
SO_2	Eye & respiratory irritant, acid rain component	Combustion of sulfurous fuels (gasoline, diesel, coal)
PM	Respiratory irritation, aggravation of asthma & cardiac v. diseases, decrease in visibility	Carbon in industrial & domestic combustion as well as fuel, industrial processes, erosion, fire, volcanic eruptions
HC/VOC	Alters respiratory system, some carcinogenic	Incomplete combustion of fuels, process distribution, use of oil, solvents chemical reaction in atmosphere
O_3	Eye & respiratory system irritation, decrease in visibility	Atmosphere reaction between VOCs and NOx, under sunlight
Source: Molina, 2000		

Air pollution problems impose significant health and economic costs. Worldwide, PM has been found to increase daily mortality, primarily from cardiovascular deaths (American Cancer Society, 1995; Six Cities Study, 1993). Some recent evidence also suggests it could contribute to premature deaths among infants (Molina, 2000). Long-term exposure could increase the chronic mortality caused by respiratory or cardiovascular diseases as well as chronic bronchitis, hospital admissions for respiratory or cardiovascular cases, visits to the emergency room for respiratory problems, asthma attacks, symptoms in the upper airways, and restricted activity days. The incomplete fuel combustion mentioned earlier also exacerbates respiratory health problems, such as asthma. Ozone also has strong effects on respiratory function, respiratory symptoms (such as eye irritation and cough) and on hospital admissions for asthma and other respiratory conditions. More information on health effects within households and residential sources is provided in Chapter 5.

CHAPTER 4. RESIDENTIAL SECTOR PROFILE

As stated above, the residential sector contributes to the air pollution in the Mexico City Metropolitan Area and is an important point of direct human exposure to pollutants. This chapter will provide more information about this Program's definition of the residential sector and sources of information about the sector's characteristics. It also describes historic sector socioeconomic and housing trends and current conditions.

Residential Project Scope

The residential sector, as defined by this project, includes all households within the MCMA and household activities such as fuel consumption and combustion and solvent usage. It includes households as defined and included by the Mexican Census and INEGI household surveys. It does not include external activities related to households such as trash collection and disposal, industry or other sector emissions caused by an increase in household product consumption or commercial operations performed within the home.

A household is defined by this project as the related and unrelated residents living in one living area or housing unit and occupants are defined as the individuals who reside in the household. In some cases, this may be more than one family. This level of analysis has been chosen because this unit will be involved with making energy consumption decisions and will receive services and pay bills as a group. Generalizations beyond this unit of measurement will not be made.

At this time, residential characteristics and data are only available at the MCMA and municipality/district level. However, other groups have tried to categorize the population by other means. Disaggregating the residential sector into subsectors would provide more accurate modeling and more specific and focused policy options. Because data was not available at this level of specificity, we were only able to model the MCMA residential sector only at the MCMA level, aggregating what data we had of more specific subcategories. However, possible subcategories are presented here for future consideration.

The Mexican Association of Marketing and Public Opinion Research Agencies (AMAI) uses a Socioeconomic Level (SEL) as a way to measure and classify the Mexican population. This variable is divided into six groups, based on household income and/or lifestyle, as shown in Figure below. As shown, the MCMA population is slightly skewed to the high and low extremes of the income/lifestyle categories.

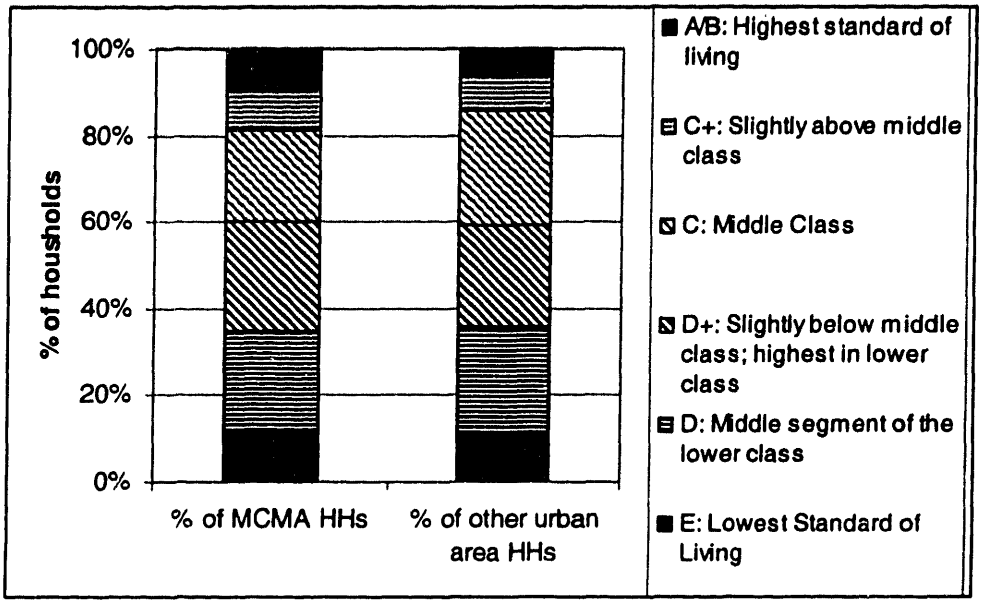


Figure 7. MCMA Socioeconomic Stratification Proposed by AMAI

Pick and Butler performed an elaborate cluster analysis, dividing the MCMA into 10 clusters based on 6 categories and 30 variables. Unikel (1975) proposed four simpler classifications for Mexico based only on population. Similarly, the Mexican census defined urban areas to be population living in localities of 2,500 inhabitants or more (Pick, 1997).

<u>Mexico City Residential Data Sources</u>

Primary sources for household characteristics and energy use data in the MCMA are Mexican government agencies. INEGI, the National Institute of Geography and Statistics, conducts a household survey every two years, collecting information on number of household members, age, migration, number of jobs, income, labor experience, occupation, number of rooms, appliances and more. The national Census, which was conducted most recently in 2000, was also used for data by municipality and delegation on household building structure, appliance ownership, tenure, and services.

INEGI representatives, however, have admitted that their database lacks a disaggregated information base and cannot be used to accurately describe households within a specific geographic region and should, at best, be used to characterize the region on average. The Census does not provide sufficient information on fuel usage and emissions sources as required by the project. Several studies (Blake & Rowland, 1995; Los Alamos, 1999; Masera & Navia, 1996; Sheinbaum & Dutt, 1996; Sheinbaum, Martinez & Rodriguez, 1996) have conducted studies that describe the current fuel and technology used in formal and informal Mexican residences, and these studies have been used when possible. Few of these studies are recent. This existing information was not consistent enough to show distinct or complete trends in MCMA household energy consumption, so we must then look to outside sources. To supplement this information, we used the preliminary survey results described in Chapter 6 and assumptions based on collaborator perceptions and assistance.

Residential Sector Profile and Trends

Using the information sources described, we were able to develop a sector profile including existing technology and energy options, penetration of appliance types and turnover rates. This information is essential for the creation of a residential model of emissions, most of which are from energy combustion. Because energy consumption has been identified as a main component of residential air pollution, it is important to evaluate what influences energy choices, demand and behavior.

The United States Energy Information Administration (U.S. EIA) has identified several indicators of American household energy consumption including (1) number of households; (2) number of household members; (3) number of buildings; and (4) amount of floor space (EIA, 2002). We have found these to be important indicators for the MCMA as well and have used them when data was available. Additionally, behavioral indicators such as length of daily occupancy, and number of employed household members can affect household energy demand. Structural factors such as building age are also important, but difficult to identify using currently available data. Several household factors including household income, size and location, thought to be correlated with energy consumption, are discussed below.

Socioeconomic

Below is a description of the historic trends of the drivers that have been evaluated to represent the residential sector. Many of these indicators have been disaggregated in order to better describe household characteristics.

Population

Mexico City's role as an urban center during the 1900s attracted migrants from rural areas, creating the primary population center of the country. It has the most sophisticated infrastructure in Mexico, the largest consumer market, the highest concentration of industries, and was the site of the national government. Mexico City essentially controlled the economy, financial system, communication networks, and government of the nation.

The population in Mexico grew from 13.6 million in 1900 to 81.2 million in 1990, 94.6 million in 1996 and over 100 million in 2002. Similarly, the population of the MCMA has grown to over 18 million people, a six-fold increase since 1950, doubling approximately every fifteen years. While national urbanization increased from 28 percent in 1900 to 71 percent in 1990, Mexico City followed a similar pattern, absorbing 36percent of the gross increase in urban population (Pick, 1997). This growth occurred for several reasons. In 1910, the hacienda system, which kept workers bound to the soil and indentured labor, broke down and mobilized many inhabitants. Natural increases (more births than deaths) also contributed.

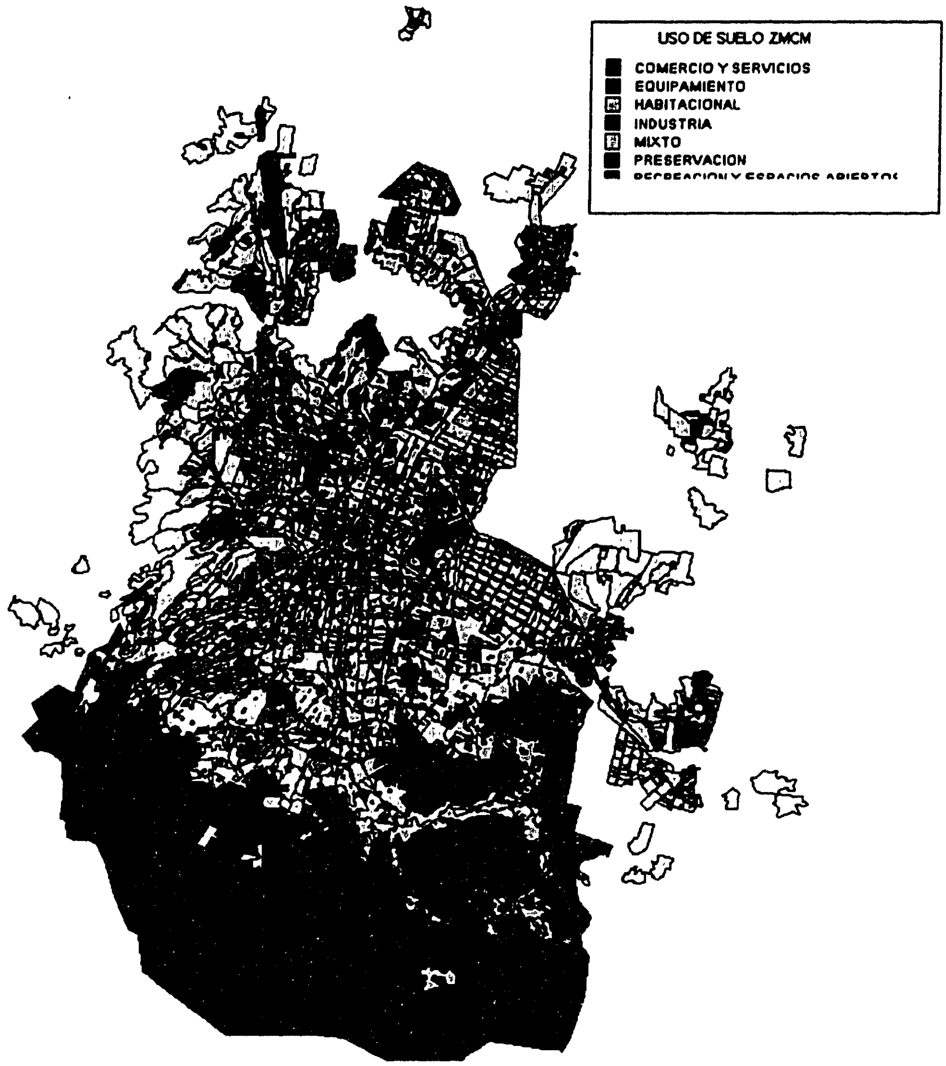
Urbanization, Population Density and Sprawl

Urbanization was found by Pick and Butler to be associated with economic prosperity indicators and inversely related with marginality and rural indicators. It is strongly associated with higher levels of education, literacy, vehicle ownership and telephones. It varies inversely with households with low income, households without toilet and electricity and households with no meat or eggs. Home ownership also varied opposite to urbanization in Mexico (Mexican urban residents tend to be renters, not home owners, but this structure is reversing). This trend leads to decreased household capability to make individual fuel choice and appliance purchase decisions.

Population density in Mexico City slightly decreased in the past century, as mentioned earlier, due to increased urbanization. The size of the urban area is currently about 1,500 km^2, a 12-fold increase since 1950; the population has similarly increased from about 3 million to about 18 million during this period. The resulting population density is around 12,000 persons per km^2 (Gilat, 2002; Molina, 2000). The size of the valley itself is 5,300 km^2. For comparison, the 1990 population density in Los Angeles, California is about 3,000 persons per km^2, New York, New York is about 10,000 persons per km^2, and Tokyo, Japan is about 13,000 persons per km^2 (Gilat, 2002; U.S. Census, 1990; http://www.chijihonbu.metro.tokyo.jp/index.htm). Population size and density have been found to be correlated (Pick, 1997).

In 1997, the DF was about 50 percent residential while the EM was about 62 percent residential. This proportion has not changed significantly since the previous decade. The distribution of land use is marked by segregation by economic and social factors. High-income residential districts are generally located far from low-income housing, in the periphery of the downtown area, and have good access to services. Figure 8 shows some of the major land use designations in the MCMA.

MAPA 7: AMCM, . USOS DE SUELO, 1997



Fuente Garza, Gustavo, La ciudad de México al final del Segundo Milenio, El Colegio de México y Gobierno del D F., en elaboración

Figure 8. MCMA Land Use Patterns, 1997 (Garza, 2000; Gilat, 2002)

Since 1950, practically all areas of Mexico City grew in population, but most was seen in peripheral areas. The greatest increase in urbanization took place in the State of Mexico, growing from an urban population of 368,0000 in 1950 to 8.3 million in 1990. The Federal District, already about 95 percent urbanized in 1950, experienced little growth.

Beginning in the 1970s, nearby municipalities in the State of Mexico began to attract Federal District residents and migrants from other states, beginning the trend of deconcentration, or urban sprawl. Within the Federal District, the northern half has historically been more populous than the southern half. Most suburban regions increased substantially in population. It is expected that semi-urban areas will continue to absorb future population growth (Pick, 1997). Growth patterns can be attributed to increasing deconcentration of the old central city and huge population gains in expanding rings around the old central city. Urban sprawl stretches the service capacity of a city, by necessitating the expansion of infrastructure. Because the physical size of the Mexico City valley is limited, urban sprawl is constrained by available and livable land.

Income

The income of residents is directly correlated to living conditions and consumption practices. Income affects the ability of a household to live in a large home, chose better fuels, purchase more types and multiple appliances and consume more energy with those appliances. At very high incomes, market-based strategies to restrict energy consumption will be less effective because households will not be constrained by them.

In Mexico, Minimum Wage Unit (MWU) is the unit for income comparison. In January 2002, 1 MWU unit was 42.15 pesos per day, where ten pesos were roughly equivalent to one U.S.$. The previous increase in MWU in 2000 to 40.35 pesos was equal to the government inflation rate, meaning no real gain for workers. The median salary in Mexico City is about three times the minimum wage (AP, 2000).

From the salary levels provided by INEGI (1998), forty percent of the urban Mexican employed force made less than one minimum wage unit, up from twenty percent in 1995. Twenty percent made between one and two MWUs, twenty percent made between two and five MWUs and only thirteen percent made greater than five MWUs. In real terms, Mexican real average incomes and minimum wages decreased over the last two decades (Sheinbaum, Martinez & Rodriguez, 1996). This decrease in purchasing power and recent energy-price increases has increased the proportion of household income spent on energy (the energy burden). For more information on energy prices, see the Chapter 5 below. In general, higher incomes are found in DF residents than EM residents.

Household Structure

Due to migration and suburbanization, we see that the population and the urban area of the MCMA has grown significantly. The number of occupants per household, however, is slowly decreasing (INEGI ENIGH, 1992-2000; Sheinbaum, Martinez & Rodriguez, 1996), causing the number of households to increase at a rate greater than population. The average household size in the MCMA is slightly more than four people (INEGI, 1996); there are approximately 4.5 millions households. Similar to the DF-EM income disparity, DF households also have relatively fewer members. The trend of smaller households has followed growth in household incomes, improvements in health care, and other trends that make it easier for household to prosper with fewer members. As household incomes have increased, so has the average size of homes. In Mexico in 1970, 40 percent of dwellings had one room, falling to 10.5 percent in 1990 (Sheinbaum, Martinez & Rodriguez, 1996). Fewer household members correlates to less energy consumption, but higher household incomes can cause a rebound effect and increase this energy consumption.

Other trends that seem correlated to growing residential energy consumption are the increase of women in the salaried work force and increased availability of electricity and water connections (Sheinbaum, Martinez and Rodriguez, 1996).

Housing Stock

The housing stock in Mexico City can provide information about the living conditions of its residents. For example, residents with lower incomes may be limited in their ability to select a fuel and more efficient appliances, even in cases where tenure provides the right to make such decisions. Poor building structures can increase instances of energy loss though the escape of heated or cooled air, or more directly though service line leakage. Lighting and other shared uses are also important sources of electricity consumption. More information on the role of the housing stock in residential conditions is provided below.

Conditions

The living conditions of households can affect residents' health, and also their priorities and preferences for improving their home. If households are crowded, or if service supply is poor, household members would typically choose to improve those situations rather than spend resources to reduce emissions.

Pick and Butler examined two measures of crowding: (1) houses with three or fewer rooms and six or more residents and (2) houses with only one room. Their findings correlated with household income data–housing units with only one room were more common in the State of Mexico, but especially in the southeastern parts of Mexico City. Crowded housing units were primarily in the west-central, northeast and southeast. Other housing deficits evaluated by Pick and Butler included no toilet, no electricity, no drainage and use of wood and/or coal. Areas with the housing and neighborhood deficits were more common in the State of Mexico, but some did occur in the Federal District.

The same study found that ninety five percent of the Mexico City population was located in three areas with favorable housing characteristics and good housing quality[4]. The areas with the best housing conditions are located close to the city center, and have relatively stable, but in some cases, decreasing population. They have labeled these two areas the Central Business District and the inner ring. There is then an outer ring area with average housing quality. Outside of these areas is a something they have labeled a transition zone. Housing characteristics differ in different parts of the city, but these houses generally have some housing deficits such as no toilet, crowding, or lack of running water. Outside of the transition zone is the periphery, where most houses have several deficits and overall low housing quality. This area has not yet experienced

[4] Many informal settlements are quite well supplied and permanent structures. Informality does not imply poor conditions.

population growth and redevelopment of its old and substandard housing. If Mexico City continues to expand outward, housing deficits may become more common.

Performing a similar cluster analysis based on social rank, the city was again defined by a core, two rings, and a periphery. Variables included in the social rank cluster analysis were proportion professional/technical/management, percentage with primary education, percent earning five or more times minimum wage and tenure status (home ownership).

The information in Table 4 below is from the 2000 Mexican Census. The EM statistics, when possible, only include those delegations considered part of the metropolitan area by the Mexico City Progra, .

Table 4. MCMA Housing Conditions

Housing Condition	DF	EM
percent homes owned	71	80
percent homes rented	28	19
percent occupants owning	74	83
percent occupants renting	26	17
percent of homes made from concrete	98	90
Ave # of rooms	3.3	2.9
Ave # of bedroom	2.1	2
Ave # of occupants	4.0	4.5
percent with separate kitchen	89	81
percent with public drainage or septic system	96	82
percent with drainage to ravine, river or lake	1	1
Source: INEGIMexico Census, 2000		

As shown, many of the characteristics are similar in the two areas. However, the EM experiences slightly poorer conditions, in terms of crowding and service availability.

Tenure

Household tenure, or degree of home ownership, affects the ability to make individual fuel consumption and household purchasing decisions. It also encourages continued structural improvements. These improvements, however, are conditional on the household having available income; many households purchase homes beyond their means, in an effort to establish a permanent residence and are then unable to maintain it to high standards (Gilbert, 2001).

Pick and Butler examined several housing characteristics. In 1990, using INEGI data, they found that the mean proportion of home ownership was about 77 percent. Contrary to the US, however, the lowest rates of ownership were found in the more affluent areas while higher rates were found in the poorer areas of the city. Home ownership was also found, unexpectedly, to be inversely correlated with primary education, high income, and proportion with professional/technical/managerial occupations.

Legislation, Regulation and Policies

Although few environmental laws in Mexico directly address household emissions and contribution to air pollution it is important to recognize the institutions and mechanisms in place if more attention was directed to this sector. This section provides a brief description of existing environmental regulations that have been developed to deal with the air pollution problem and comments on how they could relate to the residential sector.

History

The environment was indirectly included in Article 27 of the Constitution of 1917 as "consideration of public good in natural resource exploitation," but it was not a focus of Mexican legislation until the 1980s and the 1990s. One result of this delay was rapid growth of industry within residential areas.

The *Ley Federal para Prevenir y Controlar la Contaminación Ambiental* (Federal Law for the Prevention and Control of Environmental Pollution) was passed by the legislature in 1971. The focus of this law was general public health concerns. Its implementation resulted in the enactment of three sets of regulations dealing with prevention and control of atmospheric pollution caused by dust and smoke, control of river pollution and regulations to prevent and control pollution of the coastal waters. The Mexican congress then passed the *Ley Federal de Protección del Ambiente* (Federal Law for the Protection of the Environment), which complemented the 1971 law by covering atmospheric emissions issues more broadly.

A 1987 constitutional amendment gave congress more authority over passing laws promoting federal, state, and local participation in environmental issues. This led to the enactment of General Law of Ecological Equilibrium and Environmental Protection (LGEEPA) in 1988 and its 1996 amendment. In contrast to previous legislation, LGEEPA addresses a comprehensive range of environmental matters including protected areas, exploitation of natural resources and protection of the environment, including atmospheric contamination, water and soil contamination, hazardous activities and waste, nuclear energy and other forms of pollution. The law sets control and safety measures, penalties for non-compliance, and guidelines for EIAs (environmental impact assessments) and addresses jurisdiction problems, matters of zoning and enforcement.

At the moment, most of the environmental regulations in Mexico that pertain to air pollution are derived from the 1996 LGEEPA amendments, and most focus on industry, vehicles, and other major emitters.

Standards

Under the LGEEPA, SEMARNAT (the Secretary of the Environment) is responsible for setting air quality standards at the federal level. States may implement standards at the local level, but these must be at least as stringent as the federal standards. Air quality standards contained in the Official Mexican Standards (NOMs) are set as maximum permissible levels (LMPs). SEMARNAT maintains all air quality information from monitoring stations and industrial release inventories in their National Information System (Sistema Nacional de Información). The agency also keeps a toxic emissions inventory on all toxic emissions permits, licenses and authorizations that it has issued.

Stationary (fixed or point) sources are those emitting large amounts of pollutants and are required to use emission control equipment and adopt an emissions control plan. Residential homes are not considered a fixed source by regulations, but are considered an area source. Homes are relatively small sources of emissions, compared to other area sources such as industry facilities, and are not directly included in regulations or subject to liability and enforcement penalties. However, the appliances, commercial products, and fuel purchased by homes, as well as the disposal of household waste and water supply are regulated. Also, land use and financial regulations may affect households' ability to build in certain areas, purchase homes, control their fuel consumption, invest in new appliances and make independent energy consumption decisions.

Jurisdiction
After the 1996 amendments to LGEEPA, jurisdiction was designated by the activity territory (e.g., underground, bodies of water, mines, air space), activity type (e.g., water works, oil, mining, hazardous waste, paint) and pollution source (e.g., fixed or mobile, industrial, commercial or for services). The federal government established the main environmental directives and guidelines and state and local governments are in charge of implementing these guidelines.

According to LGEEPA Article 5, the following activities are under federal government jurisdiction: transportation, storage, recollection, handling, treatment and final disposition of hazardous waste; industrial and commercial activities defined as highly hazardous; the issuance of NOMS; the management and oversight of federally protected natural areas; the prevention and control of environmental emergencies and contingencies, the assessment of the environmental impact of industries under federal jurisdiction (i.e. water works, communications, oil ducts, petroleum industry, cellulose, sugar, concrete, electric industries, and mining), air pollution from fixed sources under federal jurisdiction and LGEEPA enforcement.

According to LGEEPA Article 11, the federal government can enter into agreements or conventions with state government in order to delegate some of their functions to the states or the Federal District. Air pollution management in Mexico City is one of these functions. Thus, both the environmental ministry of the Federal District and the environmental agency of the State of Mexico are in charge of regulating emissions in the MCMA.

Stakeholders
As described above, a number of federal and state governmental agencies en[illegible]e environmental laws, regulations, administrative orders, and standards in Mexico. These agencies have different degrees of power, jurisdictions and objectives. Most importantly for Mexico City, part of the metropolitan area is within the jurisdiction of the state of Mexico and another part is within that of the Federal District, which has its own state-

level government. Both of these states have their own environmental agencies with different sets of guidelines and goals. The stakeholders that are most closely related to the residential sector are briefly described here.

SEMARNAT

SEMARNAT, the main federal environmental agency, has responsibilities that include the setting of standards, establishment of ambient air quality criteria and maximum permissible levels for emissions from industrial sources and vehicles, and issuance of permits for industrial facilities under federal jurisdiction. SEMARNAT must consult with the Ministry of Finance (Hacienda) when trying to change tax policy, or introduce regulations that would have significant economic impacts. Such constraints to changing tax policies are important considerations when developing mechanisms to change energy prices to encourage reduced consumption or fuel switching.

State and Local Governments

State and local governments are also given the responsibility of light industry, vehicle use, zoning, monitoring system operation, and emergency planning. Both the State of Mexico and the Federal District have state-level ministries with jurisdiction over local environmental issues. Both states have health ministries concerned with health, the medical system, and preventing illnesses, including that from air pollution. Different conditions and regulation in the DF and EM could prevent harmonization of policies to improve air quality.

Metropolitan Environmental Commission (CAM)

The state and national governments have begun to work together to reduce pollutant emissions and concentrations by creating organizations with responsibility for implementing emission reduction plans. The current version, called the CAM (Metropolitan Environmental Commission), was created in 1996. Its job is to coordinate between SEMARNAT and the governments of the Federal District and State of Mexico. CAM's membership includes several national government agencies, including SEMARNAT, the ministries of Commerce and Industry, Health and Energy and Mining. It also includes major energy stakeholders, such as Pemex (the state-owned oil company). The key players, however, are drawn from the state governments. The president of CAM rotates every two years between the EM and DF governors; the technical secretary rotates between the EM and DF environmental ministers.

To date, there have been three air quality plans developed, which are described later:

- PICCA (1990-1995); and
- PROAIRE 2000 (1995-2000); and
- PROAIRE 2010 (2003-2010) – draft.

CAM is partially funded by its member institutions but also depends on funding from outside institutions, including the World Bank, to continue operation and to enable implementation of environmental plans such as PROAIRE.

Other Governmental Ministries and State-owned Corporations
The national government's Ministry of Energy has jurisdiction over several state-owned energy companies, including Pemex (oil and gasoline) and the Federal Electricity Commission (CFE)(electricity). Pemex has responsibility for oil and gas drilling, refining, and transport within Mexico. It generates a significant fraction of total revenues for the national government and, because it is state-owned, is subject to political control for issues such as fuel prices.

CFE is the primary state-owned electricity company; Luz y Fuerza Centro (LFC) is a second, small, state-owned company that generates power in Mexico City. CFE generates nearly all of the electricity in Mexico, and is the only company allowed to sell electricity to the public. CFE faces similar political concerns as Pemex, but does not generate the same profit. CFE and Pemex would be heavily involved with any policies to affect fuel production, sales and pricing.

Unlike oil and electricity, there is some private involvement in the natural gas market, especially in pipelines, storage, and sale to end-users. The National Energy Regulatory Commission (CRE) regulates private sector participation, granting thirty-year permits based on competitive bidding. Pemex supplies the natural gas to these private distributors.

Private Industry
Most of the larger industries in the MCMA fall under federal supervision. However, smaller industries in the State of Mexico and the Federal District fall under the jurisdictions of their respective governments. More stringent Federal District regulations have led smaller, more mobile industries to move into the city periphery in the State of Mexico. Residential demand for material goods affects industrial production and related air emissions. Location of industries and associated environmental and health risks are also a concern for residents.

Commercial and Informal Sector
The commercial sector is composed of small businesses that are regulated and are required to pay taxes. The informal sector consists of generally smaller businesses (e.g., workshops, street vendors, stores), sometimes located in the more impoverished parts of Mexico City, which normally do not pay taxes and are not regulated by labor or environmental laws. The informal economy accounts for almost 50 percent of urban jobs in Mexico (Molina, 2000; OECD, 2000). Some informal sector activities are based in residential homes and will affect household energy demand and other polluting activities.

Residents
The major stakeholders in the air pollution issue in Mexico City are the people exposed. Community participation in Mexico City has risen since the recent elections and the end of one-party rule by the Institutional Revolutionary Party (PRI). Prominent, and sometimes extreme, community groups active in the environment in Mexico City include Centro Nacional de Comunicacion Social (CENCOS), and Allianza Civica. Also active are the Mexican Environmental Law Center and Naturalia, which have filed several

complaints with SEMARNAT for violating its mandate. Although general citizen concern about the cities' air pollution is common, awareness of in-home behaviors that affect pollution and exposure is questionable.

Air Quality Programs

As mentioned above, there have been three primary air quality programs for the MCMA: PICCA 1990-1995, PROAIRE 1995-2000 and PROAIRE 2002-2010, which is still in draft form. This section will describe each of these, as well as other programs that affect air quality and which may be incorporated into PROAIRE measures or developed independently.

PICCA

The first integrated air pollution control program called "Programa Integral Contra La Contaminación Atmosférica (PICCA)", in which 41 measures are described, was issued in 1990 and covered the period from 1990 to 1995. PICCA was jointly implemented by the Government of the Federal District,, the Government of the State of Mexico, and the Ministry for Urban Development and Environment, supported by Pemex and the Mexican Petroleum Institute (IMP). Major program elements included updating Pemex refineries and increasing the stringency of vehicle technologies and emission standards. There were no measures directed at the residential sector.

PROAIRE 1995-2000

PROAIRE 1995-2000 (PROAIRE 2000), the Program to Improve Air Quality in the Valley of Mexico, included technical improvements in four major areas: transportation, industry, combustible fuels and service establishments. The air pollution control measures were financed by both the public sector and the private sector, with strong support from international banks and donor agencies.

There were two measures in PROAIRE 2000 that were directed, in part, at the residential sector. Both related to the use of LPG: (1) technological improvements to reduce emissions during commercial and domestic distribution, storage and use and (2) industrial, commercial and residential LPG market modernization to decreased emissions and increased efficiency. No evidence of specific activities undertaken as part of either measure was available.

PROAIRE 2002-2010

PROAIRE 2002-2010 (PROAIRE 2010) is being designed by the Environmental Ministry of the Federal District and CAM with the help of MIT's Integrated Program for Urban, Regional and Global Air Pollution. It will address issues such as the emissions inventory, emissions modeling, exploration of alternative fuels, improvements in monitoring the environment and health, reducing emissions from industries and services, power plant modernization, lowering vehicle emission standards, promoting public transportation, controlling the exploitation of natural resources and reducing erosion. In summary, PROAIRE 2010 is an expansion of the sets of options set forth in PROAIRE 2000, which were not implemented. A draft has been developed, and, because it was delayed, is now a program for the years 2002-2010. A final version has not yet been distributed.

The key PROAIRE 2010 measure directed at the residential sector called for emissions reductions from LPG in MCMA domestic installations. Another was to promote the use of solar energy instead of fossil fuels for water heating. Several general measures were also focused on health effects and awareness, environmental education and conservation of natural lands that will affect urban form and irregular settlements[5].

Other Programs and Policies

In addition to the three metropolitan air quality programs described above, there are several other efforts that directly and indirectly effect air emissions from the MCMA residential sector. They range from regulations, such as creation of energy efficiency standards for appliances, to small-scale pilot projects initiated in other parts of Mexico.

Energy Efficiency

The Mexican government has implemented a few regulations and programs to directly affect domestic energy consumption. CFE, the Institute of Electricity Investigations (IIE), the National Association of Appliance Producers (ANFAD) and other energy-related and appliance manufacturer organizations participated in discussions to promote efficiency standards for household refrigerators and air conditioners. These discussions resulted in estimation of energy savings for the next 20 years given efficiency improvements. A labeling program for refrigerators was also established, showing annual energy consumption in kilowatt-hour (kWh) and costs in pesos.

The National Commission for Energy Conservation (CONAE) is the agency in charge of establishing appliance efficiency standards. Other organizations in charge of energy efficiency are the Program for Energy Conservation in the Electricity Sector (PAESE), and the Commission for Electricity Efficiency (FIDE). PAESE was created in 1989 as a separate entity within CFE and aims to provide local support for energy efficiency programs. FIDE is a revolving loan-trust fund to save electricity created in 1990. Some of the programs they have developed are described below

Normas Oficiales Mexicanas (NOM). Energy efficiency norms are the federal government established standards mentioned earlier, which have been developed for a few residential appliances, including refrigerators and air conditioners. However, these standards are less stringent than those in the United States and the types of equipment included are much fewer. The IIE is currently under contract to study the technical and economic aspects of minimum energy efficiency standards for appliances.

Efficiency and Demand Side Management. Several small-scale and pilot demand side management (DSM) programs have been put in place in Mexico including programs on residential lighting, financial incentives, summertime savings, and thermal insulation.

[5] A complete list of the options proposed in PROAIRE 2010 can be seen at: http://www.sma.df.gob.mx/publicaciones/aire/proaire/proaire.htm

FIDE is in charge of certifying appliances for electric efficiency and has partnered with government agencies in several Mexican cities to create demonstration programs providing consumers with energy saving devices. The largest of these was ILLUMEX, a FIDE program whose goal is to promote electricity savings through promotion of the use of compact fluorescent lights (CFLs. The most recent demonstration project (1995-1997) was located in Guadalajara and Monterrey but has not been extended to Mexico City because of opposition from CFE (Molina, 2001). In these two cities, FIDE offered CFL lamps at 60 percent of their value to residential users who could purchase up to six lamps per household. Consumers paid 12 percent initially and the balance will be added to bimonthly energy bulls. CFLs can significantly increase energy efficiency compared to incandescent bulbs. The study in Guadalajara and Monterrey estimated that the 1.5 million incandescent lamps replaced by CFLs were able to defer 78 megawatts (MW) of new peak generating capacity and save 135 gigawatt-hours per year (GWh/yr) of electricity (Sheinbaum, Martinez and Rodriguez, 1996; Friedmann and Sheinbaum, 1998). Current CFL prices are much lower than at the time of this demonstration project.

As air conditioning becomes more common, increased focus should be directed towards increasing building insulation and the use of passive solar energy and more efficienct air conditioners. FIDE's Horario de Verano is a summertime-savings program that attempts to address this increasing demand; high volume consumers can volunteer to have their air conditioning units turned off for a short period of minutes during the summer when peak demand is too high (FIDE, 2002).

Since 1991, CFE has been promoting insulation of roofs in Northern Mexico by providing financing to high consuming homes. A small survey showed average household electricity consumption reductions of 20 percent from this program.

Fuel Substitution

Pemex has historically supplied most of the residential fuel, but recently new market entrants have made natural gas more available. The Energy Ministry is also supporting improvement of natural gas supply infrastructure (Juarez, 2001). Infrastructure availability and stability is important; residential household energy users are particularly vulnerable to supply disruptions and cost fluctuations because of their inability to change their energy sources or technology.

The Mexican government has initiated a program to increase electricity and LPG prices, and essentially align LPG with an international price. The reliance on an international LPG price is important because fuel prices in Mexico are regulated. The electricity tariff structure, originally containing seven prices, depending on the amount consumed, has recently been switched to only three increasing block rates (Friedmann and Sheinbaum, 1998). There is also a fixed charge and a monthly increase. Four guidelines have been established to promote energy efficiency with social equity: (1) minimum energy services guaranteed to low income population; (2) changes in energy prices must be linked to demand side management programs in order to allow access to efficient technology; (3) a new residential electricity tariff should reduce subsidies for medium and large consumers; and (4) electricity bills should be simplified and made more user-friendly (Foss, 1996).

Despite pricing efforts described, pricing signals may not presently be a switching incentive. During the past twenty years, energy prices have fluctuated dramatically and the relative prices of fuels changed often (Sheinbaum, Martinez & Rodriguez, 1996), making decisions regarding fuel switching uncertain. One report (Foss, 1996) concluded that pricing has historically been controlled for political reasons, and even recent efforts to allow pricing of LPG to be market based have not shown any identifiable effects of natural gas substitution. This could be for several reasons, including the tendency for customers to withhold payment for their fuel and a high rate of theft. As a result, the actual price paid by customers is probably less than the reported price. Policy makers would benefit from improved knowledge on the potential impacts and effects of their fuel-related decisions.

Solvent Use Reduction

Solvents used in the home contain VOCs that contribute to ozone and secondary partulate formation. Many less-volatile paints, finishes, stains, insect repellants and other solvents are now commercially available in Europe, the U.S. and other countries. Water-based paints, for example, are available in Mexico. There are also numerous homemade recipes for household cleaners and other products that contain no toxic ingredients. Fact sheets on where to find toxics on your home, how to handle household hazardous waste and prevent exposure and substitutes for household solvents are available from almost every U.S. state environmental agency and from the U.S. EPA[6]. Awareness and education are the best ways to increase use of such substitutes and reduce household exposure to these products. Information is also available for substitutes for garage and home workshop solvents, which would be applicable for many informal activities conducted in MCMA homes.

Other Alternatives

Some recent research has shown that several common houseplants can reduce the amount of some organic chemicals in the air. Other studies have found that the moisture in the soil and the soil itself causes the greatest removal (DuPont, 1989). However, since the air inside a house is changed so frequently (about once every one to two hours), plants would have to remove the pollutants at a rate that is significant in comparison to the removal by ventilation.

The presence of a combustion appliance alone does not, in itself, indicate a problem. A more general approach to reducing energy consumption through demand side management is through education of energy consumption and alternatives and changing consumer behavior. It is unclear whether such an education campaign has taken place at any scale in Mexico City. However, in a 1992 Gallup poll, 71 percent of the people in sixteen countries, including Mexico, said they were willing to pay higher prices for products if it helps protect the environment (Wapner, 1996).

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[6]http://www.deq.state.or.us/wmc/hw/factsheets/HouseholdHazardousWaste.pdf; http://es.eap.gov/techinfo/facts/safe-fs.html.

Some of these policies were selected for modeling in the residential model, as described below.

CHAPTER 5. RESIDENTIAL EMISSION SOURCES

Without examining the causes of emissions, this chapter describes in detail the documented sources of residential emissions and the effects of those pollutants. This information guided development of the residential model.

Emissions Inventory

To effectively model residential sources of air pollution, we must first develop an accurate profile of the sector. I used the emission inventory as a starting point. Figure 4 above was the 1998 CAM Emission Inventory estimates for all sectors; the graph is shown again here for review. According to these estimates, the residential sector is a relatively small emitter in all categories except hydrocarbon emissions.

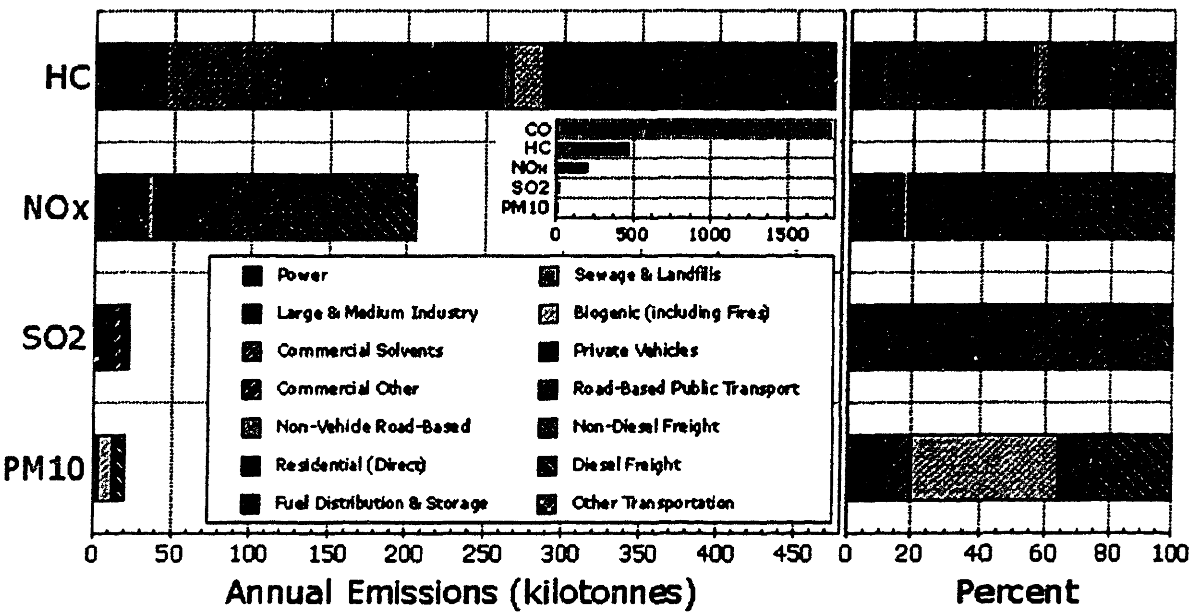

Figure 9. 1998 MCMA Emission Inventory (CAM, 2002)
Image designed and provided by Stephen Connors.

The Emissions Inventory and the chart illustrating it above misrepresent the residential sector's contribution to the MCMA's air pollution since it does not include several important residential emissions sources. The first is residential wood combustion. The inventory documentation (Table A.3.18) estimates that two PJ of wood (three percent of total non-electric residential energy demand) was burned in 1998 for residential cooking and water heating, but for some reason it does not include any emissions from this combustion in the inventory itself (ERG, 2002)[7]. Another missing component is residential solvent consumption. Households use solvents for several purposes such as cleaning and painting. While solvent consumption and emissions is estimated for commercial use, the inventory does not include residential use. These two omissions are important to consider when using the CAM Emission Inventory as a baseline.

[7] Even this small percentage of wood use would be a large contribution to residential emissions.

Using this same inventory, but keeping in mind its flaws, Figure 10 shows the percentage of non-transportation air emissions (all five criteria pollutants are shown) produced in the residential sector. The "other" category includes non-vehicle road based, sewage and landfill and biogenic sources. Units are in thousand tonnes (kilotonnes).

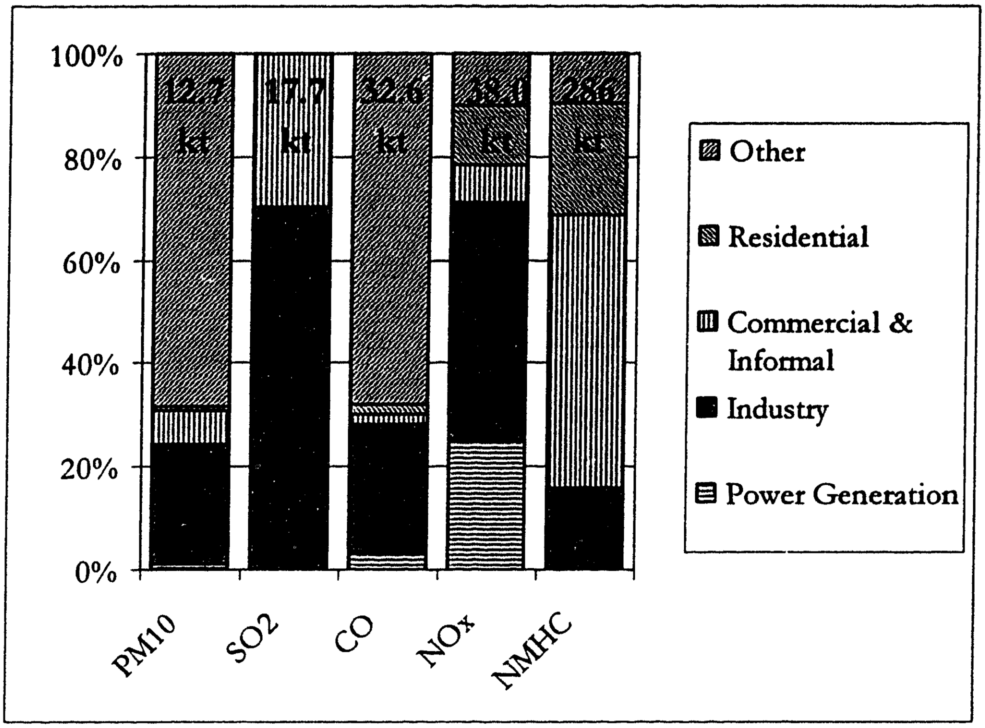

Figure 10. 1998 MCMA Non-Transportation Emission Sources (CAM, 2002)

By narrowing the categories to only non-transportation sources, the residential sector is now shown to play a role in NMHC, NOx and CO emissions. We must remember that this inventory omits residential wood combustion and solvent use. Most of the NMHC emissions are from fuel leakage and solvent consumption. The NOx and CO emissions are fuel combustion byproducts.

Narrowing our scope further to only the residential sector, Figure 11 presents the documented emissions sources.

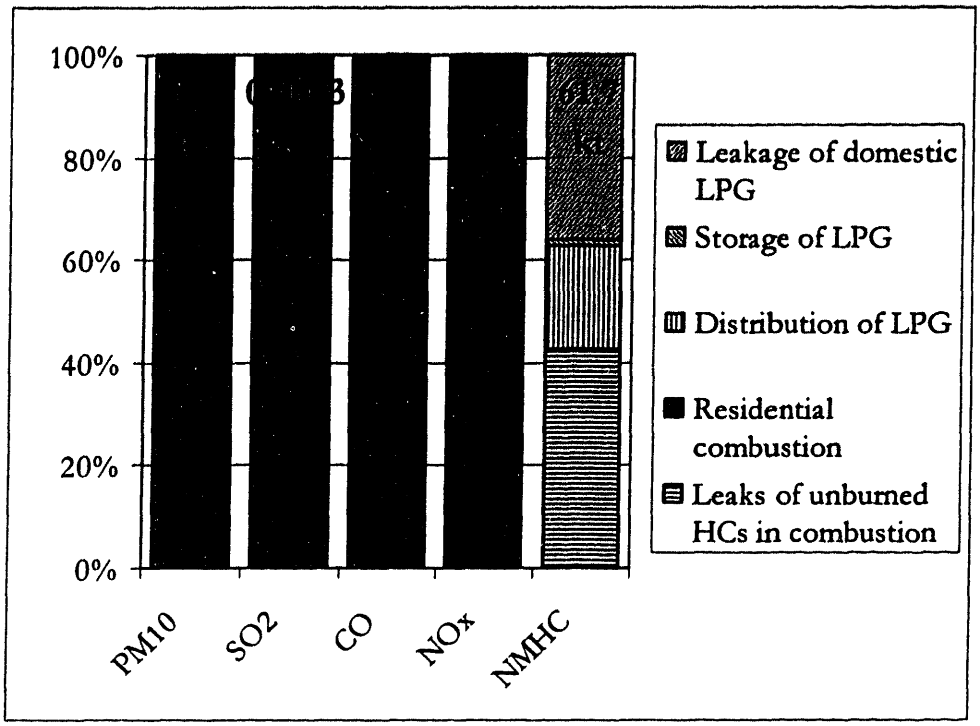

Figure 11. 1998 MCMA Residential Emission Sources (CAM, 2002)

As shown, all emissions of PM10, SO_2, CO and NOx are the result of fuel combustion. NMHC emissions are divided between LPG related sources and other fuel leakage.

<u>Indoor Air Pollution</u>

As mentioned earlier, one of the reasons that the residential sector is important to consider, in a way that other sources are not, is that there is the potential for direct and close-range human exposure to pollutants. The impact on human health varies with the category of combustion pollutant, but exposure efficiency is greatest indoors and therefore has a large effect on human health than pollutants outdoors or released a larger distance away. Emissions within the closed environment of the home can be trapped indoors, limiting dispersion and increasing this exposure. The primary health effects of local air pollutants were described earlier in Chapter 3, but more detail is provided here on indoor effects.

The release of pollutants in the home may result in more severe effects than those described above. For this reason, indoor air quality (IAQ) is increasingly becoming a source of human health research (Ellegard, 1997; EPA, 2000; EPA, 2002c-h; Portney and Mullahy, 1990). Some have found that, the levels of indoor air pollution in developing countries are orders of magnitude higher, and affect a larger number of people – especially women and children – than in developed countries (Ellegard, 1997). Several respiratory and chronic obstructive lung diseases (COLD) in developing countries have been attributed to the higher levels of indoor pollution (Kandpal, Maheshwari & Kandpal, 1994). Additionally, burning of wood in open fires, as is often practiced in informal settlements where several families share the same cooking equipment, can result in respiratory diseases among rural dwellers, especially among women and children (Sheinbaum, Martinez and Rodriguez, 1996).

Indoor pollutants affect short- and long-term respiratory function and blood oxygen levels. Immediate health effects due to indoor air pollution, such as eye, nose and throat irritation, headaches, dizziness and fatigue, can show up after a single exposure or repeated exposures. Symptoms of some diseases, including asthma, hypersensitivity pneumonitis, and humidifier fever, may also be exacerbated. Long-term health effects include respiratory diseases, hearth disease and cancer (EPA, 1995).

There are several sources of urban and residential air pollution; the primary two are fuel combustion and volatile organic compounds (VOCs). Following is a more complete description of each of the primary residential combustion-related air pollutants, including information on pollutant characteristics, sources and health effects.

Combustion Pollutants

Combustion sources are easier to pinpoint because they come from specific sources but both are important to human health. Combustion occurs when any fuel or material is burned. Its byproducts can adversely affect the health of building occupants and can affect local, regional and global air pollution. The residential sector is unique because of it has the most direct link to both of these. When a carbon-based product is burned, the fuel combines with the oxygen in the air to yield carbon dioxide, nitrogen oxides, water vapor and other compounds and gases that are potentially toxic. When these gases are not vented to the outside, they can build up to unsafe levels. In Mexico and the US, there are no indoor guidelines for these pollutants so all health effect assessments refer to outdoor air guidelines.

Incomplete combustion can result in the release of carbon monoxide (CO), nitrogen oxides (NOx), particulate material (PM) and non-methane hydrocarbons (NMHC). The combustion products are released under conditions where incomplete combustion can occur, such as non-electric cook stoves, water heaters, clothes dryers and heaters.

Although many combustion appliances contribute to indoor pollution, the presence of a combustion appliance does not necessarily indicate a problem. Often, improper operation and maintenance are to blame for elevated indoor levels of combustion pollutants.

The combustion pollutants of the greatest concern for residential air pollution include nitrogen oxides, carbon monoxide, sulfur dioxide, respirable particulates and volatile organic compounds.

<u>Nitrogen oxides</u>. Nitrogen oxides (NOx) are a family of gases that include NO and NO_2; each is a product of high-temperature combustion. NOx is also a fine particulate and ozone precursor. Because liquid and gaseous fuels generally burn at a higher temperature than solid fuels, NO_2 is generally associated with gas and liquid fueled appliances. The residential fuels associated with the highest emissions of NOx are solid fuels (mostly fuel wood), LPG and then NG.

Information on NO_2 shows exposure at levels higher than 1.5 parts per million (ppm) can cause symptoms such as irritation to eyes, nose and throat, respiratory irritation, increased airway resistance and some lung impairment. Exposure to levels greater than 10 ppm causes debilitating illnesses such as pneumonia and bronchiolitis and may lead to chronic lung disease (EPAc-h, 2002; Molina, 2000).

Controlled human exposure studies and epidemiological studies of homes using gas stoves have shown altered lung function and acute respiratory symptoms and illness, despite typical residential levels less than 0.2 ppm. Continuous pilot lights and the use of kerosene heaters were found to increase the indoor concentrations significantly (DuPont, 1989). Again, children have been shown to be more susceptible than adults in United States and Britain scientific studies.

Carbon Monoxide. Carbon monoxide (CO) results from the incomplete combustion associated with a low-temperature flame. Because solid fuels generally burn at a lower temperature than gaseous and liquid fuels, CO is generally associated with solid fueled appliances. However, malfunctioning gas and liquid fueled appliances can also produce CO.

CO is a colorless odorless gas that reduces the ability of oxygen transport in the body and therefore acts as an asphyxiating agent. Common symptoms to low-level exposure include dizziness, dull headache, nausea, ringing in the ears and pounding of the heart. If unconsciousness occurs, damage to the central nervous system, the brain and the circulatory system could result. Young children and persons with asthma, anemia, heart and hypermetabolic diseases are more susceptible (EPAc-h, 2002; Molina, 2000).

Unfortunately, there is little information on the long-term health effects of exposure to the relatively low concentrations of CO (<50 ppm) typically found in residential settings. However, some studies have found that is due to lack of reporting and not lack of effects (DuPont, 1989). Some indoor CO concentrations are due to infiltration of outdoor air into the home and some results from improper ventilation of gas appliances. The amount of CO in the indoor air is dependent on the tuning of the appliance and the amount of use (number of burners, number of continuous pilots).

Sulfur Dioxide. Sulfur dioxide (SO_2) is a combustion byproduct associated with most fossil fuels. Solid fuel is the residential fuel that produces the most SO_2, but all others produce small amounts as well. SO_2 is also an acid depository and fine particulate precursor.

Sulfur dioxide can be smelled at levels of 3-5 ppm and upper-airway irritation is detected at levels of 8-12 ppm in some individuals. Among more sensitive individuals, such as exercising asthmatics, irritation and bronchioconstriction can occur at levels as low as 0.25-0.5 ppm. The irritating effects of SO_2 may make the lungs more susceptible to addition effects from other pollutants (EPAc-h, 2002; Molina, 2000).

Particles. Particulate Matter (PM) is tiny particles that are suspended in the air and is formed primarily from dust and the products of fuel combustion. Solid fuels contain more complex and non-combustible materials than gas or liquid fuels, and result in the release of more particles and complex organic contaminants. However, LPG combustion does produce some particulates.

Combustion particulates also affect lung function. Larger particles (PM10) can be expelled from the body before reaching the lungs, but smaller respirable particles (PM2.5), able to be taken further into the lungs, present a greater risk. Particles can also be carriers of contaminants or mechanical irritants that interact with chemical contaminants (EPAc-h, 2002; Molina, 2000).

Ozone. Ozone (O_3) is formed from the combination of VOCs, NOx and sunlight in the atmosphere. As mentioned in Chapter 3, a study by Blake and Rowland presented evidence of the link between LPG leakage and O_3 concentrations. A recent Mexico City newspaper article cited this study and stated that LPG leakage from all MCMA sources (leaking about 76 thousand tonnes annually) is responsible for 15 percent of ozone formation in the MCMA air (Ochoa, 2002). Over ninety percent of LPG consumption and leakage is from the residential sector.

At ground level, ozone smog and particulates can cause problems, such as decreased visibility, but also health problems related to respiratory function including chest pain, eye irritation, headaches, lung function losses and asthma attacks (EPAc-h, 2002; Molina, 2000).

Volatile Organic Compounds

Non-methane Hydrocarbons. Non-methane Hydrocarbons (NMHCs) can be released through combustion or volatized. Organic compounds that exist as a gas, or can easily off-gas under normal room temperatures and relative humidity, are considered volatile. The residential sector is the primary source of volatile organic compound (VOCs), mostly non-methane hydrocarbon (NMHC), emissions that pose significant health problems. There are hundreds of VOCs in commercial products, but only about 50 have been commonly identified in indoor air (DuPont, 1989). Examples include formaldehyde, benzene, acetone, phenols, aromatic hydrocarbons and alcohols, some of which are carcinogens.

Symptoms attributed to VOCs include respiratory distress, sore throat, eye irritation, nausea, drowsiness, fatigue, headaches, and general malaise (Hansen, 1991). Some are also mutagens and carcinogens (DuPont, 1989). Due to the large number of chemicals and other materials found indoors, it is difficult to establish any definite causal link between health and certain VOCs. Industrial exposure studies have, at high concentrations, documented respiratory ailments, heart disease, allergic reactions, mutagenicity and cancer to some VOCs. However, it remains almost impossible to determine the health effects associated with the relatively low concentrations of VOCs in indoor air (EPAc-h, 2002; Molina, 2000). Another portion of the Mexico City Program is currently conducting indoor exposure assessments within the MCMA.

Some of the major sources of indoor VOCs are photocopying materials, paints, gasoline, personal hygiene and cosmetic products, building materials, molded plastic containers, disinfectants, cleaning products and environmental tobacco smoke. Few VOCs are unique to any one source. Indoor concentrations of VOCs are generally much higher than outdoor levels. It should also be noted that the typical peak residential VOC concentrations are often tens to thousands of times lower than current workplace standards. A common exception is chemicals used in large quantities for cleaning. This does not mean, however, that the workplace standards are necessarily protective of human health, or that the compounds do not have a synergistic or additive effect. Also, the workplace standards are designed for healthy adults, not at risk populations such as the elderly, children or asthmatics.

There is little to no information available for VOC-related product use in MCMA households. Additionally, this source of air pollution is absent from the MCMA Emissions Inventory. For these reasons, more attention has been placed on modeling indoor combustion sources, but VOC sources have been included and are intended to be a larger focus in upcoming program research.

Other indoor pollutants
Other sources of indoor air pollution include asbestos, bioaerosols, tobacco smoke, radon, noise and other environmental conditions. Because these are not directly linked to regional or larger air pollution problems, they were not within the scope of the project. If, however, the aim of the Program becomes more focused on individual well-being and health, it may require further evaluation of small-scale conditions.

Residential Energy Use

As shown in the above section, the pollutant emissions from residential fuel combustion are over 60,000 tonnes per year. The residential sector consumes about 16 percent of the energy in Mexico (EIA, 2001). The energy demand in developing countries is expected to grow at higher rates than in industrialized countries (Mulas & Bazan, 1999).

The primary source of air emissions produced by the residential sector is fuel combustion (both within the home and through power generation). Any attempt to mitigate air pollution emissions from the residential sector should focus on energy consumption, which will therefore be the focus of this research. There is a need to determine indicators and predictors of household energy consumption, to develop policies and strategies that can affect this behavior. This section will address this need and describe the current use and sources of residential energy consumption.

Residential Energy Studies

During the past three decades, several studies have been performed in an attempt to identify predictors of energy consumption in households (Guerin, 2000). The first report to examine this connection was a study by Seligman et. al. (1978) which related occupant behavior to energy use. Examining primarily studies performed within the past 15 years, most agree that occupant energy behavior has a major influence on the amount of energy consumed (Andrade, 2001; Emery & Gartland, 1996; Melasniemi, 1992; Soderlund, 1990; Weihl & Gladhart, 1990). Several long-term studies, including Brandon & Lewis, 1999, have shown that many households have been able to reduce their energy consumption and expenditures while living in the same home, especially after receiving feedback related to financial or environmental costs of consumption. Weil & Gladhart (1990) found that occupant energy consumption behavior is very patterned, but that these patterns vary considerably from one household to the next. Schipper (1994) found that occupant behavior is a more significant driver during periods of stable energy prices and supply, a goal of Mexican officials (Juarez, 2001).

The household characteristics linked to energy consumption in these studies included age, income, home ownership (hereafter referred to as tenure), education, number of occupants, physical size of house, daily occupancy rate, appliance/home technology ownership, gender and the presence of a home handy person. The survey chapter below describes which of these were selected in this project.

Guerin (1992) described a systems theory approach to studying household energy consumption, having adopted this methodology from previous studies using the human ecosystem model. The human ecosystem theory states that interactions occur within the human ecosystem between the human organism and its three environments: the natural environment, the social environment and the designed environment. The characteristics of each environment and the human organism affect energy consumption. Other studies simply measured energy behaviors and the outcome of these behaviors directly. All emphasize the role of energy consumption indicators, which can be used to design effective energy consumption reduction policies.

Mexico City Household Energy Use

Not only are more households gaining access to delivered energy, households are using more energy than ever before. In Mexico in 1983, 35 percent of households consumed less than 50 kilowatt-hour (kWh) electricity per month; this number had fallen to 20 percent in 1991 (Sheinbaum, Martinez and Rodriguez, 1996). The same study has found similar trends in other less developed countries (LDCs). The Mexican residential sector composes between one-fourth and one-fifth of the final national energy demand (Sheinbaum, Martinez and Rodriguez, 1996; Bazan, 2000; EIA, 2002). This consumption grew at approximately three percent per year between 1970 and 1990. Within the MCMA, this share is about the same (11 percent in 1992 – Sheinbaum and Dutt, 20percent in 1996, Bazan) with a larger share of the electricity use. For many of the reasons described in this paper, such as increasing population, urbanization, and appliance saturation, the energy demand for this sector is expected to continue to grow.

MCMA household energy consumption is the result of four primary end-use activities: cooking; water heating; lighting; and appliance use. Household fuel options include liquid petroleum gas (LPG), natural gas (NG), electricity and some solid fuel, but availability of some of these fuels is limited by supply infrastructure and high prices. LPG has historically been the fuel of choice for most non-electric end-uses but natural gas is also used for cooking and water heating and some clothes drying and heating. In

Mexico in 1990, about 40 percent of all household energy consumed (petajoules – PJ) was LPG and about 40 percent was fuel wood, although this share has decreased from about 70 percent in 1970. The remaining 20 percent was composed of electricity, natural gas, and oil. These values differ for the MCMA, a primarily urban area that with generally improved access to more formalized fuel such as LPG, natural gas and electricity. Electricity generation is supplied by five power plants in the MCMA (20percent) and several outside of the area. Solid fuel (usually fuel wood - FW - or biomass) is occasionally used for cooking and water heating.

Cooking and water heating use the majority of non-electric fuels, primarily LPG. Non-electric fuels are also used for lighting, drying and heating in small amounts. Appliances are all electric, as is the majority of lighting. Almost all homes have cooking, lighting and some appliances. About sixty five percent have water heaters, and much fewer have their own clothes dryers or heaters. Smaller saturation values are common in the EM, compared to the DF.

Figure 12 shows the percentage of households using each fuel for each end use, highlighting this trend towards LPG use.

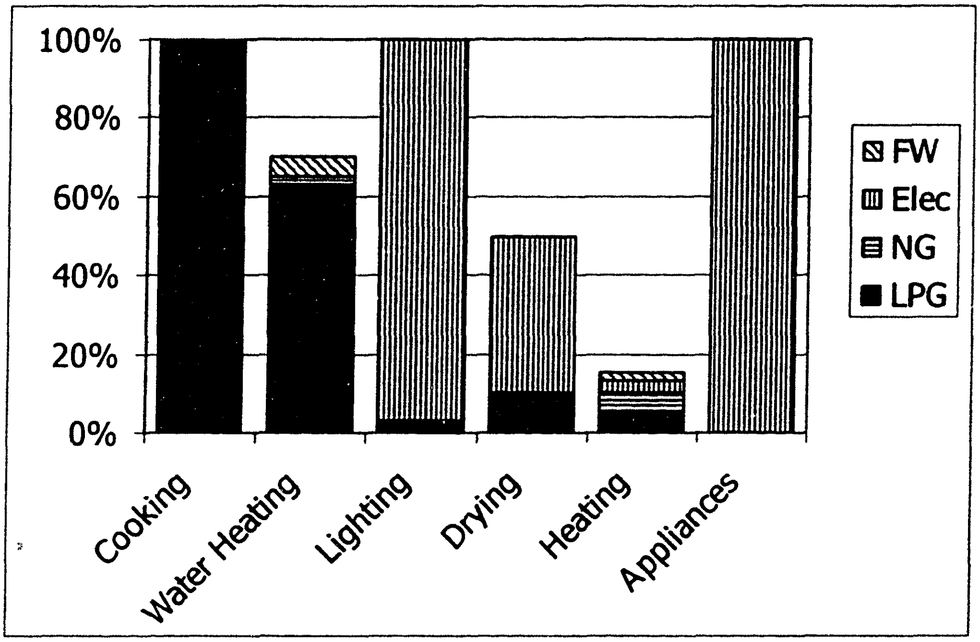

Figure 12. 1996 MCMA Household Saturation of Major Fuel Combustion Sources by End Use (INEGI, 1998)

The remainder of this section provides more information on each fuel and end-use.

Residential Fuel Types

This section provides more information on each of these residential fuels: their use; supply; pricing structure and combustion emissions characteristics. Figure 13 shows the 1998 consumption for each of the end-uses and fuel types. Most of the fuel consumed by households in the MCMA is LPG, followed by electricity. This figure (and others later) does not include fuel consumed for the production of electricity; only final electricity energy is counted as residential electricity consumption[8].

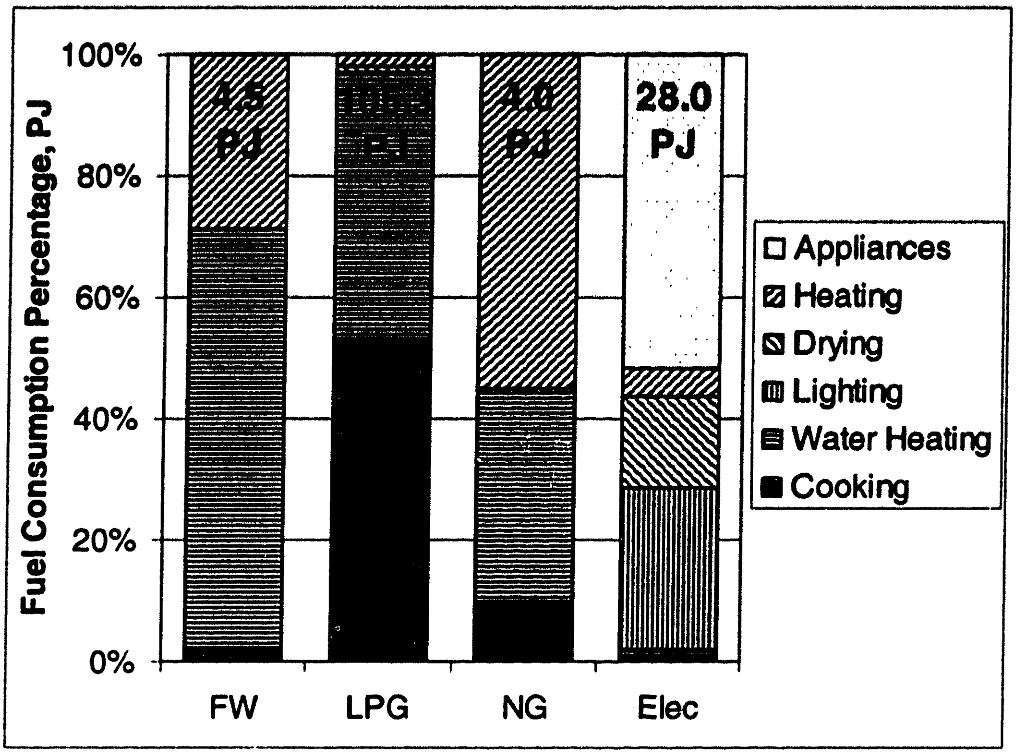

Figure 13. 1998 Residential Fuel Consumption, by fuel type, As Modeled

Fuel Wood. Although seldom used in urban areas, fuel wood (FW) is still used in some of the irregular and low-income settlements on the periphery of the MCMA. There is little fuel wood readily accessible in the valley, so it must be transported from a distance.

Because of the informal nature of fuel wood, it is difficult to identify accurate data on its use. Anecdotal evidence from program participants leads to the assumption that little to no wood and/or other solid fuels such as coal is being used. However, INEGI cites that less than percent of urban area households use these fuels for cooking (1996). Pick and Butler (1997) found that, in 1990, approximately eight percent of homes in Mexico City used these fuels "occasionally or daily" and that these fuels may be an unmeasured source of pollution. Peripheral areas in the northeast and southeast showed higher levels of fuel wood use (83 percent for cooking and/or heating in Ecatzingo) than the rest of Mexico City (Pick and Butler, 1997). The use of this fuel was also found to be correlated to other housing deficits such as crowding and lack of a toilet. Overlooking solid fuel use results in a significant underestimation of pollutants in the Emission Inventory.

[8] For every 1 kwh of electricity produced (3.6 MJ consumed by residents), about 11 MJ of primary energy is consumed by power plants.

The use of fuel wood contributes to deforestation as well as releasing large amounts of several air pollutants when burned. Burning fuel wood produces more emissions of each pollutant per unit of energy than any other residential fuel.

Liquid Petroleum Gas. Liquid Petroleum Gas (LPG) is used by over ninety percent of MCMA households for cooking, water heating, clothes drying or space heating. In Mexico overall, the saturation values differ, primarily because of a lower average household income. However, the number of households that use LPG increased from 52 percent in 1970 to 71 percent in 1990 and about 90 percent in 1998 (INEGI, 2000; Sheinbaum, Martinez and Rodriguez, 1996).

The residential sector comprises over 70 percent of LPG demand in Mexico and 85 percent of demand in the MCMA (Bazan, 2000). The Mexican LPG market is the largest in the world, and continues to grow around four percent per year (Bauer, Quintanilla and Riveros). The MCMA accounts for about 20 percent of the Mexican demand. Other oil products used in households, but in minor amounts, include kerosene and fuel oil.

LPG is both inexpensive and simple to transport and supply; it is stored in interchangeable cylinders and/or gas tanks fixed in buildings. Trucks offer the exchange of empty cylinders for filled ones every few days. Households usually have a spare cylinder. Higher income households have fixed tanks, refilled periodically by tanker trucks. In apartment buildings, where large fixed tanks may be shared, each apartment can be metered separately for its consumption and billed accordingly by the building administration or by dividing the total building consumption by the number of living units. The continuity and reliability of fixed tanks is higher than for changeable tanks, and is similar to that of piped natural gas. If no one is home when the supply truck arrives with changeable times, service could be interrupted. This unreliability may promote conservative behavior at times when the tank is near empty.

During the late 1970s and early 1980s, real prices of LPG and kerosene fell more than 10 percent (Sheinbaum, Martinez and Rodriguez, 1996). After 1982, the Mexican government moved towards a more market-based economy and reduced energy subsidies, causing LPG prices to rise. Since that time, prices again fell, and then rose, creating an uncertain market for consumers.

LPG is primarily composed of propane and butane. LPG sold in the MCMA differs from the LPG available in the United States, containing a much larger percentage of butane[9]. These oil-derived products are relatively unreactive VOCs and contribute to local air pollution. LPG combustion produces emissions of all criteria pollutants considered, but is a higher emitter of NOx and PM10 than is natural gas, its largest competitor. However, LPG is a slightly lower emitter of CO, SO_2 and HC than natural gas.

The system of storage, transportation, distribution and use of fuels, primarily LPG, is another key source of emissions of non-methane hydrocarbons (NMHC) through leakage

[9] MCMA LPG is 61 percent propane 39 percent butane; US LPG is 95 percent propane 5 percent butane (2000 PROAIRE; July 2002 conversation with Rodrigo Favela, Pemex.

of unburned fuel. More than three quarters of these emissions are generated in domestic installations. The importance of fuel delivery as an emissions source is highlighted by Blake and Rowland's measurements of propane and butane in MCMA air, described earlier, has encouraged the inclusion of an option in recent metropolitan air quality plans to reduce LPG leakage from fuel transportation, storage and use.

Natural Gas. Natural gas (NG) can be used for many of the same residential purposes as LPG, but it is not yet at the same level of penetration within the MCMA for two primary reasons: LPG has historically been less expensive than LPG and the NG infrastructure does not yet reach the majority of residential areas. An additional factor is that NG increases the risk of explosion from pipeline damage during earthquakes. In 2000, the residential sector comprised only about two percent of the total MCMA NG demand (Bazan, 2000).

Combustion of natural gas produces slightly more emissions of HC, CO and SO_2 than LPG, but far less PM10 and NOx. It also has greater energy content than other available residential fuels.

The two companies responsible for NG distribution are the Pemex subsidiary Diganamex and Pemex Gas y Petroquimica Basica (PGPB). Residential suppliers are Metrogas and Mexigas. Once the fuel is commercially available, stoves and water heaters using LPG can be switched to NG with a simple retrofit, performed by the NG service providers. Consumers' bills consist of an acquisition fee and a distribution fee, which are based on consumption, and an additional service charge and tax.

Electricity. In 1996, 23 percent of Mexico's total electricity sales was consumed by the residential sector. During the past decade, the number of residential electricity end-users has grown at an average of five percent per year in Mexico[10] (Sheinbaum, Martinez and Rodriguez, 1996). In Mexico, the number of households with access to the electricity grid increased from 59 percent to 88 percent from 1970 to 1990. Values in the MCMA are assumed to be slightly higher because it is urban. INEGI data shows that over 99 percent of MCMA homes have electricity. Unlike the case of fuel wood, this value is closer to that of Pick and Butler, who found that only four percent of Mexico City homes did not have electricity in 1990. However, in some municipalities in the northeast and southeast this value can be as high as 13 percent. There is also evidence of residents attaching private lines to electricity distribution lines and using electricity without payment.

The Mexican government has implemented a program to increase electricity and LPG prices. The tariff structure has three prices, depending on the amount consumed, in addition to a fixed charge and a monthly increase. Tariffs cover about half of the cost of service. For large consumers, the tariff can be higher than the cost of service, making efficiency efforts uneconomic as consumers still pay the tariff cost (Friedmann and Sheinbaum, 1998).

[10] Between 1967 and 1996, Mexican residential sector electricity demand grew on average by 8percent per year (Friedmann and Sheinbaum, 1998).

Emissions due to residential electricity consumption do not occur in the home, but do cause large ambient releases of NOx, CO, and PM10 through electricity generation. Additionally, local power plants, when run at capacity, supply only about 20 percent of the current electricity demand for the MCMA. Generation units outside of the valley satisfy the remaining demand. Therefore, any growth in electricity demand will not directly affect local pollution.

Solar. Studies have shown that surface solar irradiation is sufficient in the MCMA to replace some fossil fuel end-uses with solar ones and is, in fact, cost effective in some cases. It is expected that a three-person household may reduce its LPG consumption one hundred percent, while for a five-person household the reduction would be 70 to 80 percent (Bauer, Quintanilla and Riveros). A small field test yielded results of LPG savings ranging from 30 to 80 percent.

The physical possibility of installing solar water heaters depends on the type of dwelling, whether private home or apartment building. Bauer, Quintanilla and Riveros's study estimated the number of private houses with LPG water heaters where substitution can be implemented profitably (i.e., no need to invest in a backup LPG system) is the number of dwellings that have LPG water heaters minus the number of dwellings in apartment buildings, assuming the latter all use LPG for water heating and that no substitution is feasible there. This yields 35 percent of the MCMA households; the amount of LPG saved for the entire area will be between 21 to 35 percent of total daily consumption.

Fuel transitions. In general, as economies improve and household incomes increase, additional fuels will become available and a residential transition from more polluting to less polluting fuels will occur. The most common progression has been from fuel wood and other solid fuels to LPG to NG and electricity and then to alternative fuels such as solar. INEGI data and other studies have shown a pattern similar to this (Sheinbaum and Dutt, 1996). A strong correlation between household income levels and the types and amounts of cooking fuel used has been found, leading to the finding of a "fuel-income ladder" to explain the shift to more convenient and higher quality fuels and as household income pass certain thresholds (Alam, 1998; Masera, 1997).

Switching to different fuels can involve a connection fee, appliance purchase costs and/or appliance retrofit costs. Policies designed to encourage such switching could provide subsidies for any of these expenditures, to make the switch more feasible for households.

Residential End-Uses

Evaluating the residential sector by end use provides a complement to analysis by fuel type. For each end-use, this section will describe ownership and fuel consumption trends, appliance types and alternative fuel availability. Figure 14 shows the 1998 consumption for each of the end-uses described.

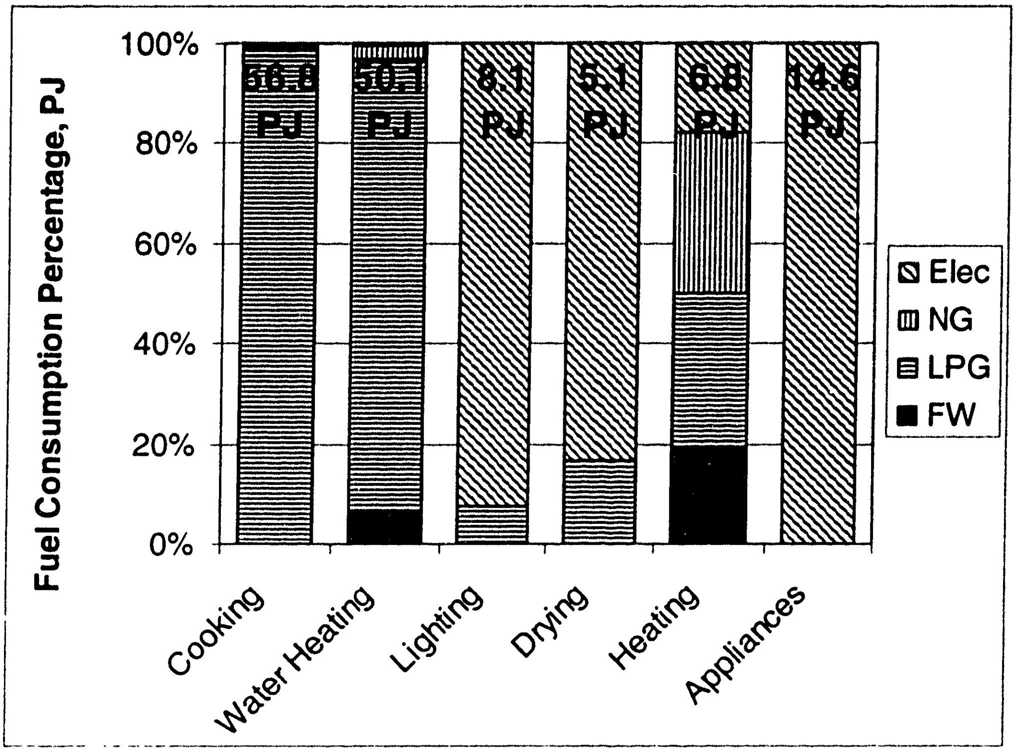

Figure 14. 1998 Residential Fuel Consumption, by end use, As Modeled

Cooking. Cooking represents the largest energy end use in terms of energy consumption, followed closely by water heating. In more rural areas, the share for cooking is increased further. Approximately 99 percent of homes in the MCMA have a stove (99 percent of these use LPG). In some cases, the same stove is used for cooking, water heating and space heating. Most stoves used with LPG and NG have four burners and an oven. Fuel wood stoves in rural areas are usually three-stone open fires that are connected to many cultural issues (Sheinbaum, Martinez and Rodriguez, 1996). While fuel wood is only used for cooking by five percent of Mexican urban dwellers, and less than one percent in the MCMA, the emissions from each PJ of wood are much larger than any other fuel, as mentioned earlier.

Water Heating. In Mexico, energy consumption for water heaters increased from 20 percent of annual household energy consumption in 1980 to nearly 30 percent in 1990, primarily because of a larger number of homes purchasing water heaters (Sheinbaum, Martinez and Rodriguez, 1996). For urban areas the increase was from 37 percent to 67 percent and in the MCMA; current saturation is around 70 percent – over 60 percent of these use LPG. The saturation of water heaters is found to be very income dependent (Sheinbaum, Martinez and Rodriguez, 1996). Water heater saturation is relatively low compared to cooking stoves because many rural homes use a cooking stove to heat water and water heaters may be shared between connected housing units.

LPG and NG water heaters are available in two basic design types: storage type and instant heaters. LPG water heaters with storage and thermostat are the type most commonly used. Instant heaters are more common in smaller apartments. Electric water heaters are seldom used in Mexico. Storage-type water heaters using fuel wood or biomass residues are also available. A water heater requires a permanent water supply so for low-income rural households, water may be heated on a cook stove instead. Over 90 percent of households in the MCMA have access to running water. According to Pick and Butler, approximately 10 percent of Mexico City homes did not have running water in 1990 (1996). Households with separate water heaters are likely to use more hot water than others that must use cook stoves to heat water.

Lighting. Lighting represents about four percent of Mexico final residential energy demand (about one-third of residential electricity demand) and about five percent in the MCMA (Sheinbaum, Martinez and Rodriguez, 1996; INEGI, 1998). It represents nearly 40 percent of residential electricity use in Mexico and 30 percent in the MCMA. Currently, most homes use incandescent lights but efforts – such as ILLUMEX described earlier – are being made to promote the use of compact fluorescent lights, which are more expensive but last at least five times longer and use about two-thirds less electricity per year.

In informal areas, non-electric lighting is provided by kerosene lamps and burning of fuel-wood and candles. Sheinbaum, Martinez and Rodriguez (1996) found that outdoor and security lighting are not significant in terms of energy consumption, but indoor lighting and lighting of common spaces is.

Appliances. Appliance electricity demand represents about 10 percent of total residential energy demand and about one-half of total residential electricity demand. Appliance saturation, including electric appliances as well as space heaters and clothes dryers that use LPG or NG, has increased dramatically during the past few decades, increasing electricity consumption per household. During the past twenty years, there has been a consistent increase in appliance ownership in the MCMA (INEGI, 1992-2000; Sheinbaum, Martinez and Rodriguez, 1996). Those with the highest saturation are refrigerators, television sets, irons, clothes washers and water pumps. More expensive items, such as refrigerators, may show income dependence. Some appliances, such as TVs, have a saturation of almost 100 percent, indicating little income dependence. However, while initial TV purchase shows little income dependence, income dependence is likely for appliances such as TVs in which a household could own multiple units. Additionally, some appliance types could be seen as optional, and their ownership shows some income dependence as well. For example, space heaters and air conditioners are owned primarily by those with higher than average income, because they are not seen as necessary in Mexico City's climate. Also, clothes washing machines are not essential in some households because hand washing is still common. Some of the housing architecture contains handwashing facilities, and domestic workers often perform this chore. Water pumps are common in the MCMA because of the insufficient water pressure many households experience. However, there is significant expense associated with pump installation because it is often necessary to construct multiple water tanks on the premises.

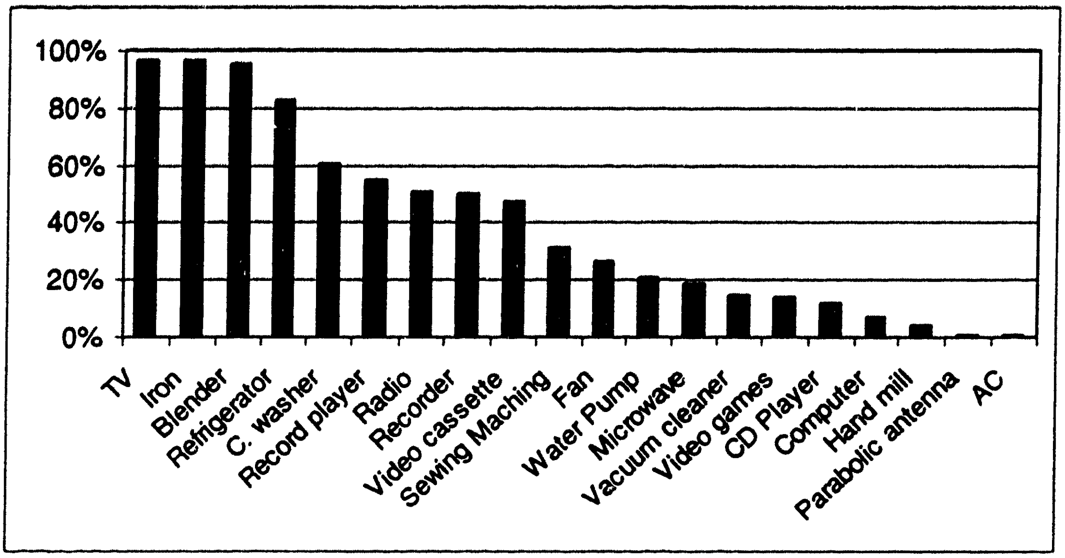

Figure 15. 1996 MCMA Residential Electric Appliance Saturation (INEGI, 1998)

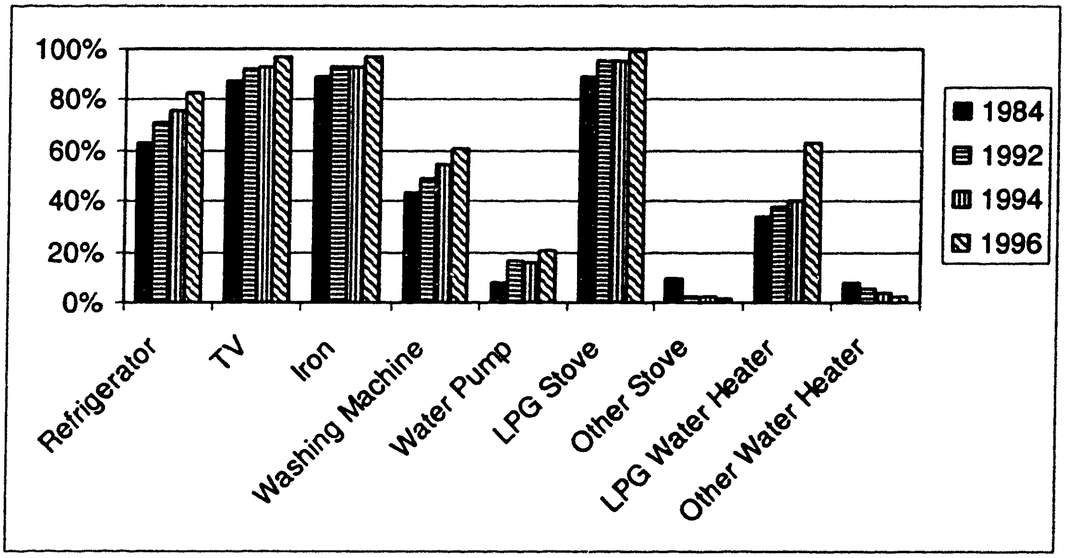

Figure 16. MCMA Residential Appliance Saturation (INEGI ENIGH data for 1984-1996)

Figures 15 and 16 highlight some of the electric and non-electric appliance trends mentioned above. The INEGI ENIGH (National Survey of Household Incomes and Expenses) did not consistently collect saturation values for all appliances shown in Figure 15, so the trends in Figure 16 are only for a select number of appliances. For almost all appliances, ownership percentages have consistently increased during the past two decades. Figure 16 shows how LPG stoves and water heaters have replaced other fuels for those purposes. Almost all households now own television sets, irons, and blenders. Over 80 percent own refrigerators, and many own clothes washers. A number of other appliances are also owned by over 50 percent of households. In terms of annual electricity consumption, air conditioners, refrigerators and clothes washers and dryers are the most intensive.

Non-Combustion Residential Emission Sources

In addition to combustion-related emission sources in the residential sector, there are several other sources that can create emissions and exposure potential. The key source is the fugitive emissions described below.

Fugitive emissions

The release of fuel and/or emissions with no combustion, or fugitive emissions, in the residential sector is primarily the result of fuel leakage, solvent use and application of fertilizers and pesticides. Each is described below.

Leakage

Table 5 below, created from CAM's 1998 Emission Inventory and the Residential Model, shows the relative contribution of LPG leakage to residential NMHC emissions. Other residential NMHC emissions are from fuel combustion and solvent use.

Table 5. Residential NMHC Emissions from LPG Leakage, 2000 As Modeled

	LPG Consumption, PJ	LPG Leakage, PJ	LPG Leakage, tonne NMHC	Distribution & Storage Leakage, tonne NMHC
Stoves	52	2.15	45,000	-
Water Heaters	44	0.3	6,000	-
Total Residential	98	2.45 (3% of resid. LPG consumption)	51,000 (51% of resid. NMHC emissions)	16,000 (16% of resid. NMHC emissions)

Solvent Use

Several attempts were made to use a bottom up approach to quantify residential solvent usage and resulting emissions. However, there is no data available on solvent production or retail solvent sales that could be used for this purpose. Adding to this dilemma was that the MCMA Emission Inventory does not include residential solvent use within any of their emission source categories. For these reasons, a literature review provided us with, what we feel is, representative per capita emission factors that would apply to the MCMA population.

Outdoor fertilizers/Pesticides, etc.

Pesticides are considered more toxic than the VOCs commonly found in indoor air (DuPont, 1989). Most health risk occurs in cases of improper application. Common symptoms of exposure include headaches, nausea, dizziness, shortness of breath, hot and cold flashes, and eye or skin irritation. Few long-term health effects have been clearly established, but several are known or suspected mutagens or carcinogens.

CHAPTER 6. RESIDENTIAL SURVEY

This chapter is designated to the residential survey, performed in November and December of 2002. First, a description is provided of the primary objectives of the survey. Then the general methodology is described, including the questionnaire design. An overview of the data analysis and preliminary results is also presented, but final and reviewed results were not complete at the time this thesis was written. Finally, possible future applications of the survey are mentioned.

Residential Sector Survey Objectives

The residential model incorporates many assumptions, such as the income and fuel price elasticity of fuel demand, the percentage of new homes that will chose a certain fuel and consumption level, the behavior of homes within different income deciles, the trend of households to switch fuels (elasticity of substitution), the presence of an energy savings rebound effect (mention earlier) and more. During development of the model, literature, government officials and program collaborators were consulted for input and best estimates, but precision is still lacking. Government data collection is not sufficient to fill in the gaps; another source of household information is needed.

To validate the model, an in-person survey of households was envisioned to gather quantitative data on socioeconomics and variation and level of energy consumption, based on the saturation (percent of households using a particular fuel or appliance) of fuel types and equipment and to be used to identify qualitative information on consumer choices and influences in energy consumption.

The survey objectives are summarized as follows:

1. Obtain a household profile (household members, appliance and fuel ownership, etc.). This will aid analysis by linking household characteristics to energy consumption and household behavior/choices.
2. Model the emissions on a neighborhood level.
3. Identify household influences and constraints to energy consumption and fuel switch (and related) decisions and the interest and capacity to change these.
4. Determine household awareness and perceived importance of the environment.
5. Serve as a test of survey applicability – whether it should be performed at a larger scale and across a sample more representative of entire MCMA.

The survey was designed as a way to obtain characteristics on fuel and appliance use and emission sources for one neighborhood. This information could then be used to create an emission profile of the area using the residential scenario model. This would allow neighborhood members to visualize their options and impacts and make more informed decisions. It was performed at a small scale as a test of the instrument and methodology because of funding and time constraints. The survey results can then be used to improve the model components, verify and determine the value of information for the model assumptions.

Another important use of the survey will be to identify correlations and relationships between household size, income, home ownership and other factors that affect energy demand and household behavior. This information on consumer attitudes and behavior will then be used to define the uncertainty of scenario performance, as described earlier. One additional benefit is the opportunity to use the survey as an educational tool to increase the visibility of domestic fuel consumption and increase occupant's awareness of the links between their behavior and local, regional and global air pollution problems. Successful outreach programs require identification of what measures will effectively change consumption behavior patterns; the proposed survey can serve to gather the information necessary for such programs. Household characteristics that affect energy consumption and related activities will also assist decision makers design effective and appropriately focused programs.

Because the desired information has never before been collected in such detail, a survey is the appropriate approach. The information is household specific and personal, validating the choice of personal interviews above other methods such as observation. Because the population is so large and diverse, an ethnography in which the researcher would live within the community would not be possible. After data collection, other methodologies have been applied for analysis.

While some of the information the survey collects is published by INEGI and other sources at an aggregate level, it is necessary to know the information for the specific households responding to this survey.

Survey Methodology

There have been a few residential energy surveys that have been performed, which were used as models to design our own. In the mid-1990's, a 3,000 respondent survey on household energy use was performed in Hyderabad, India (Alam, 1998), focusing on the connection between household income and the transition from traditional to modern household fuels and the policy implications and energy market. Around the same time, in Bath, U.K., 120 households were followed over nine months, in an effort to track fuel consumption and identify ways to increase domestic awareness of the links between their behavior and fuel consumption related problems (Brandon, 1999). Eighteen months of field research in Uttara Kannada District, Karnataka State, India was performed to determine cooking and water heating consumption seasonal and location variability (Ramachandra, 1999).

The most thorough and complete residential survey that has as similar focus and methodology as the one we are undertaking is the U.S. Energy Information Administration's (EIA) annual national survey – the Residential Energy Consumption Survey (RECS). It is used to obtain information on the use of energy in the residential housing units in the United States. As with our survey, it includes information on the physical characteristics of the housing units, fuels and appliances used, household demographics, energy consumption and expenditures and other information that relates to energy use. The first RECS was conducted in 1978 and the most recent was conducted in

2001. The latest was a survey of almost 5,000 households selected to statistically represent 10.7 million housing units in the United States. Analyzed data on current characteristics and trends is presented on the EIA website. Unlike our survey, however, RECS does not ask questions aimed at understanding residents' perceptions of the impacts of energy consumption and priorities for improving air quality.

Below is a description of the steps to designing and performing our residential energy consumption survey. At each stage, several precautions were taken to ensure the survey was representative, accurate and valid.

Sample Selection

According to the U.S. Census Bureau (1993),

> *"A household includes all the persons who occupy a housing unit. A housing unit is a house, an apartment, a mobile home, a group of rooms, or a single room that is occupied as separate living quarters. Separate living quarters are those in which the occupants live and eat separately from any other persons in the building and have direct access from the outside of the building through a common hall. The occupants may be a single family, one person living alone, two or more families living together, or an other group of related or unrelated persons who share living arrangements."*

This project will use this definition. A literature review has demonstrated that many household characteristics have been examined as predictors of energy consumption behavior and energy consumption change. Because this proposed survey would be performed for the first time, we are presently more interested in the former. The two household variables most often correlated with energy consumption are household income and tenure. Several studies, including Schwartz and True (1990) and Xiaohua and Zhenmin (2000) found that family income is positively related to home energy consumption. Many more found that home ownership (tenure) is also a strong predictor of energy consumption behavior (Guerin, 2000). The survey will be representative of the entire MCMA, but these two characteristics will be a focus for stratification.

Approximately 400 household surveys were performed, limited by time and budget considerations. At this stage, only formal households were analyzed in the survey. Because of the large number and inaccessibility of irregular (informal) settlements in the area, capturing these inhabitants in the project would be too challenging. Another, although less onerous, difficulty was to gain access to formal settlements because of language barriers. I do not speak Spanish and have utilized the assistance of the program's Mexican partners to review the questionnaire and acquired the services of a Mexican firm to perform the survey.

The firm will be sampling using the distribution shown in Tables 6 and 7 below. Geographic and income stratification was required to ensure that the survey respondents would be representative of the entire formal MCMA. It should be noted that the income clusters will not be used to determine correlations between income and energy

consumption – individual household income levels, occupation types, commercial activities within the home, household size and other indicators will, instead, be evaluated.

Table 6. Survey Distribution of Municipalities and Delegations

Municipalities/Delegations	**Number of Surveys per Municipality**	**Total Number of Surveys**
Ecatepec, Neza, Iztapalapa and Gustavo A. Madero	11	44
Naucalpan and Tlalnepantla	10	20
48 municipalities and delegations (remaining municipalities)	7	336
		400

Table 7. Survey Distribution of Age and Income level

Age / **Socioeconomic**	**18-25 years**	**26-35 years**	**36-45 years**	**46-55 years**	**56 years or more**	**TOTAL**
High	16	16	16	16	16	80
Medium	32	32	32	32	32	160
Low	32	32	32	32	32	160
TOTAL	80	80	80	80	80	400

Socioeconomic information was retrieved from Association of Marketing and Public Opinion Research Agencies (AMAI). To satisfy the desired representation of the MCMA, municipalities and delegations were selected intentionally. Within each, neighborhoods were selected randomly. In every neighborhood, a block was then randomly selected. Houses were systematically randomly selected, and the interviewers begin knocking door to door until an interview is granted. Once an interview is held, the interview skips two houses and begins knocking door to door again. This process is repeated until the required number of interviews has been performed.

In each home, the respondent will ask to speak to the head of the household, who makes the purchasing decisions[11]. The sample will have a 95 percent confidence interval with a margin of error of ±5 percent.

<u>Question Formulation and Organization</u>

There has recently been extensive research related to the question-response process (Czaja, 1996; Kalton, 1982). Questions must be written with the research goals in mind, so the respondents cannot only provide the information we want but that this information is accurate and readily accessible. Questions must be concrete and specific enough to elicit the desired data. According to this literature, survey questions must:

[11] Ideally, all household members who contribute to household decisions would be present, but this would add too much complication and time to the process at this stage.

- Measure some aspect of one of the research questions
- Provide information in conjunction with another variable
- Be understandable by the respondent
- Ask about information possessed by the respondent
- Ask about information the respondent is willing to provide
- Ask about information necessary to analyzing one of the research questions

There was a concern that the respondents would not know an answer or would answer even if they could not control the behavior they were predicting. We would request that the person who pays the energy bills and makes the consumption decisions be the survey respondent. In addition to this request, a screening question at the beginning of the survey to determine eligibility for the study was included.

When necessary, qualifiers were used in the survey questions. In some cases, a specific reference period for the question was provided. In others, respondents were asked for their summary judgment, using qualifiers such as "approximate", or "overall." Adjectives and other restrictions were also used, limiting the respondents to a category such as "better than" or "worse than". Finally, the questions may limit respondents to certain reasons for behaviors. For example, "*To reduce your monthly energy bill,* would you change your household energy consumption?"

For one section, response quantifiers were also used, asking respondents to rank several items from 1-5. This question was included because we are interested in household opinions. It is recognized that the terms "very polluting" may have different connotations for different respondents. To better gauge their meaning, such rating questions could be followed by a question asking the main reason for this rating; this has been done when possible.

There were several steps taken to ensure understanding and complete responses. Response categories were kept simple but were exhaustive of all possibilities. Where necessary, additional categories to cover all the possibilities, such as "other (please specify)" or "I don't know" were included. These general categories help reduce nonresponses. Questions asking for respondent agreement or disagreement were purposefully excluded, even though this format is popular. There is a tendency towards agreement, regardless of the questions content. Efforts were made to use language (such as income categories and housing types) similar to other household surveys and censuses performed in Mexico City by the government. The questions were organized by subject matter. Each section contained a very brief introduction, so that respondents were aware of the general content. The first section was relatively easy – containing factual questions about the household. The final section was perhaps the most difficult for the respondent because it contained opinion questions.

Pretesting and Review

Pretesting the questionnaire determines if the instrument works in the manner intended and if it provides valid and reliable measures. Time and monetary resources limited the amount of pretesting but several, small pretests were performed. Draft questionnaires were distributed to Mexican MIT faculty and student program members. These respondents completed the survey so that response time could be measured and also provided feedback and suggestions on the questionnaire content and its appropriateness for Mexico City residents. The pretest helped eliminate some questions that the respondent was unlikely to know, and helped reword and reorganize others if the desired answer was unclear. Other MIT faculty members experienced in survey performance reviewed the questionnaire and assisted in framing the questions to prompt accurate responses, determine statistically valid samples. Finally, the firm performing the full-scale survey performed a 40 survey pilot test and refinements to the questionnaire were made based on the results.

<u>Data Collection Method</u>

The consulting firm in Mexico City hired to perform the survey also reviewed the questionnaire for appropriateness and helped ensure a high respondent rate using methods that have worked in previous household surveys they have conducted. The surveys were conducted in person, face-to-face.

A self-administered method was eliminated because of the length of the survey – respondents would get tired or confused by the survey and results may be inaccurate. If mailed to the respondents, this type of survey also typically has a lower response rate. Performing the survey over the telephone was eliminated because this would cause sampling bias – by municipality, telephone ownership rates range from 45-88 percent in the DF and from 1-66 percent in the EM (INEGI, 2000 Census). Excluding those homes without telephones would lead to response bias and unrepresentative results.

Face-to-face, or personal interview, surveys have several advantages. Respondents are often more focused and able to concentrate on the survey. Additionally, they may feel more responsible to give accurate answers because they are in the same room as the interviewer. This method is preferred for certain questionnaire items and issues of data quality.

To ensure a high level of quality response data, several steps were taken regarding the interviews, as suggested by survey design literature. While a face-to-face interview allows more complex questions to be asked because an explanation and visual aides is possible, questions and answer choices were kept short and fairly simple. This enables the respondent to keep all of the information in mind. The questionnaire contains primarily general household information and behavioral questions and will take 30 minutes or less. In the field, the survey actually took between 30 and 40 minutes, which is slightly long but still acceptable. The interviewer is also able to encourage more detail with open-ended questions and offer explanations if necessary. If questions are long or confusing to the respondent, the interviewer can allow them to read it themselves. Because of the higher comfort level (respondents are in their own home, are not holding a telephone receiver, long pauses are not uncomfortable) with face-to-face interviews, the questionnaire can also be longer. Additionally, the respondent has the opportunity to consult their records or other household members if information is unknown. Because of the personal nature of this method of surveying, personal or private questions were not included in the questionnaire. One disadvantage of this method is that respondents are more likely to provide socially desirable responses (Czaja, 1996). This was a possibility in our survey when asking about willingness to pay more for a more efficient appliance and similar questions. However, efforts were made to make these questions objective. Questions that related to illegal acquisition of fuel was written so that it did now apply directly to the respondent but to people the respondent knows – they were permitted to include themselves in this category but they were not singled out.

It is important that interviewers match respondents by nationality and language (Czaja, 1996). Face-to-face surveys typically have a higher response rate than other methods for a couple of reasons. Additionally, it is more difficult to refuse an interview face-to-face.

Sampling frame bias is usually low in the face-to-face method because recent census data is used to develop the sample population. Response bias is also low because the data is collected directly by the interviewer and most respondents will cooperate. The interviewers have more control using this method than any other; they can suggest changing location or removing distractions if necessary. This method also allows the interviewer to develop a rapport with the respondent, because they can see who they are talking to.

To ensure accuracy, these interviewers were properly selected, trained and supervised. They read the questions verbatim and were assumed to record the responses accurately and not bias the survey in any way. They are also trained to be courteous, attentive and to build rapport with the respondents.

Questionnaire Description

The final survey consists of seven sections, as follows:

Section 1: Household Profile. Section 1 will provide a complete profile of the household, to relate to responses in later sections. Questions are asked related to resident education, household income, length of residence, building characteristics and more. These factors influence household energy consumption.

Section 2: Household Commercial Activities. Section 2 will provide a small amount of information on commercial/informal activities going on in homes. It will help expand the household survey, because these activities can affect household fuel and appliance choices and energy consumption.

Section 3: Household Appliances. Section 3 will provide information on household appliances. It will continue to develop the household profile and identify appliance characteristics affecting energy consumption such as type, number and age of appliances owned. It will also provide information on the decision process of purchasing appliances, to identify how these decisions can be influenced to reduce energy consumption.

Section 4: Household Fuel. Section 4 will provide information on household fuel choice and use. It will continue to establish the household profile and identify fuel consumption, expenditures, choices and conditions. Information on stove burners, pilots and other features relates to LPG leakage and reduction options, such as included in the 2002 PROAIRE. This section will be used to answer such questions as: How much are consumers willing to spend to reduce consumption? How much do consumers know about fuel availability, pricing, safety; pollution? What causes consumers to choose the fuel they use? All of these answers will help formulate realistic scenario options.

Section 5: Household Solvents. Section 5 will be used to enhance the residential sector scenario analysis because the emissions inventory currently overlooks residential solvent use as an emissions source. The answers will help determine the importance of this category.

Section 6: Household Outdoor Activities. Section 6 will be used to enhance the residential sector scenario analysis because the emissions inventory currently overlooks residential pesticide and fertilizer use as an emissions source. The answers will help determine the importance of this category.

Section 7: Household Awareness. Section 7 will be used to characterize the attitudes of the households, in terms of their perceptions of the air quality and their role in its change. This section will be used to answer such questions as: Will they pay for improvements? Do they know that work is being done? Questions are asked at MCMA, neighborhood and work locations to gauge if they perceive air pollutions problems to differ by location. The last question is used to evaluate interest in this problem and whether feedback and an information campaign would be a valuable future policy option.

For the full questionnaire text, please refer to the Appendix.

Preliminary Survey Data Analysis

A complete review of the survey results was not yet performed at the time this thesis was published, so only preliminary results are presented here. These results should not be considered final; they were not used in the residential model as factual but only to reduce uncertainty in cases of unavailable data. Some of the initial, general findings are:

- About 20 percent of households conduct some type of commercial activity in their home.
- Most households buy new appliances, as opposed to used ones.
- About one-third of households have detected fuel leakage from stoves and water heaters and feel that this is important
- Almost all households are willing to spend slightly more for less polluting appliances and to reduce fuel leakage.
- Most households listed price is the most important consideration when choosing a fuel.
- Most households feel that fuel dependability is lacking, except for electricity.

- Most households recognize that in-home activities contribute to air pollution, which they feel is average or poor in the MCMA.
- Ninety percent of households would like to receive more information on reducing air pollution from their home.

Survey Future Steps

The next step is to conduct a thorough evaluation of the survey responses and preliminary results. The survey methodology and data will be peer reviewed and analyzed before final results will be presented and published.

The survey will remain the possession of the Mexico City Program, to be fine-tuned and reused if performed correctly and with desired results. In this way, initial data and information can be collected for my immediate purposes and analysis, but the survey can continue to be used to evaluate long-term trends and policy effectiveness.

If performed at a larger scale and at regular intervals for the Mexico City Program or the Mexico City or Mexican government, the survey could serve additional purposes (beyond the five objectives listed above):

A. Use to verify INEGI household survey responses and link household characteristics (income, appliance ownership, etc.) to household behavior/preferences.
B. Use to find information on irregular settlements, which are poorly represented in INEGI and other surveys.
C. Use to direct future research towards primary residential sources of energy consumption and air pollution.
D. Use by policy makers to design effective policies. For example, if fuel price does not affect consumer decisions a policy that would increase fuel price to decrease its use or subsidize fuel price to encourage switching to alternative fuels would not be effective.
E. Use as an evaluation tool enabling government to provide information/feedback to consumers on impacts of energy consumption and methods of energy and monetary savings.

If time and resources permit, the survey could be used as a foundation for research of irregular/informal settlements in the MCMA, as mentioned above as Objective B. These settlements are more disperse and community oriented than formal settlements and are often unregulated. Due to the nature of these settlements, the questionnaire survey instrument described above would not be practical. Instead, qualitative interviews with residents would be more beneficial. Often, many households within these settlements would share cooking areas, commercial enterprises and other activities, so questions on the type of stove they own would not work. In these cases, questions worded to ask about their source of hot water and how they prepare food is more appropriate.

CHAPTER 7. RESIDENTIAL MODEL

A primary goal of this portion of the Mexico City Program is to create sectoral models of the MCMA, in order to guide decision making for air pollution reduction strategies. One component of this was to create a residential sector model, to be used to model the sector independently and as part of the Integrated Scenario Analysis. This chapter will describe the process of this analysis and then provide detail on the residential sector model that has been created – its attributes and many moving parts.

Integrated Scenario Analysis

Each sector of the metropolitan area has been modeled independently, to estimate total future emissions and costs from that sector given several alternative futures and combinations of pollution control options. Efforts were made to ensure consistency across models and depictions of futures. The results of each modeled sector are then viewed in combination with one another, to develop a depiction of the entire MCMA and its potential for air pollution mitigation and the costs associated with that mitigation. This paper does not describe this aggregation, but focuses on the residential sector.

Residential Sector Model Overview

I have developed a detailed, bottom-up Microsoft Excel model that can estimate air emissions trajectories from the residential sector. Population and household characteristic projections were used in conjunction with estimates of energy intensity of the end-use (e.g., energy use per person, per household, per appliance), saturation of the end-use, and end-use units (e.g., population, number of households, number of appliances) to estimate several possible future scenarios.

A twenty-six year study period, from 2000-2025, was selected because of its correspondence with the Mexico City PROAIRE time frame, and because it was short enough to be within the planning horizon and permits long term planning and results. A long time frame also allows for evaluation of emission reduction options with varying deployment schedules. Additionally, many of the health impacts of interest have certain latent and lag periods that may not be identified with a shorter study period.

First, a reference case was developed to represent current trends including population and income changes, autonomous fuel choice changes and equipment efficiency improvements and existing air pollution control programs. Next, the modeling involves selection of several options representing possible emission reduction strategies such as a promotion of increased switching to less polluting fuels, availability of Energy Star (U.S. Environmental Protection Agency higher efficiency) appliances, repair and retrofit of leaking stove pilots and more. Scenarios are then developed which model the incorporation of any combination of these options. For the reference cases and all scenarios, the cost to the residential sector is also calculated. Costs include residential fuel and equipment purchase costs and installation costs when applicable.

The model was then used to estimate emissions across these reference cases, emissions control options, and three possible futures. Different futures were included because the growth path of the Mexico City, its economy, physical layout, population and other characteristics – is unknown. Decision makers would be more able to select robust control strategies and develop beneficial policies if they have information on the robustness of options across several futures.

Government decision makers will be able to use this model, which can stand alone to represent the residential sector of the MCMA and can be used with the other sector models to form an integrated scenario analysis covering all MCMA air emission sources to evaluate the emissions reductions and costs of various policy options and alternatives.

Modeling Equations

Microsoft Excel is the primary software used to construct the Residential Sector Model. The sector was analyzed using a bottom-up model that individually estimates the emissions by each of the energy-related end uses and non-combustion emission sources described earlier.

Combustion

The bottom up approach models residential energy consumption for a given end use as a product of several parameters: energy intensity of the end use (EI_i), the saturation of the end use (S_i) and the number of aggregate units. For the residential sector, the aggregate unit is a household. The basic equation, based on Sheinbaum, Martinez and Rodriguez (1996), used to model these emissions is:

$$\Sigma EI_{ij} * S_{ij} * HH * EF_{j\,k} = EM_{ij\,k}$$

where:

- EI = energy intensity (unit energy consumption), PJ/yr
- i = end-use
- j = fuel type
- $_k$ = pollutant
- S_{ij} = saturation of end-use, percent of households
- HH = total number of households
- $EF_{j\,k}$ = emission factor, tonne/PJ
- $EM_{ij\,k}$ = emissions, tonne/yr

The equation was used for each end-use (i) – fuel combination (j). The total is an estimate of residential combustion emissions for a given year. For example, for cooking using LPG, the energy intensity is the average annual use of LPG per household (assumes amount of use by household); the saturation is the percentage of households using LPG for cooking and the aggregate units is the number of households in the MCMA. For appliances, the energy intensity is measured as the unit energy efficiency (kWh/yr). This energy consumption value (PJ/yr) is then multiplied by the pollutant emission factor for combustion of LPG to get tonnes of emissions/yr. This process is repeated for each end-use, energy type and pollutant of interest.

Non-combustion

Added to combustion emissions are the non-combustion sources of residential emissions described earlier – LPG leakage and solvent use. LPG leakage had been documented during use, distribution and storage. All three sources have been included in the residential model. Leakage of unburned LPG from distribution, storage and residential use was modeled using CAM's Emission Inventory Methodology. They have identified emission factors for storage, distribution, eight points per piece of equipment, use of pilots and ignitions of stoves and water heaters, and leakage from stoves and water heaters when not in use. Using these factors, an estimation of the number of LPG stoves and water heaters and their respective type of ignition, total leakage was calculated. Residential solvent usage has also been modeled using per capita emission factors found in emission inventory literature. Details on the modeling process are provided below.

Data Sources

An important constraint to using a bottom up, activities-based approach was the availability of reliable and complete data for individual end-uses. The data requirements of this model are significant. Primary sources used were described earlier in Chapter 4. Uniform and complete historical data, so that past trends can be calculated and future trends estimated, is limited. Specific sources are described in the following section on model inputs.

Additionally, this calculation could be performed for the total MCMA or for portions segmented by household income, household location (urban versus rural), or other characteristics, if information was obtainable. Segmenting the model in this way by municipality or neighborhood would provide more detailed estimates of individual household contributions to the air pollution problem, allowing neighborhood action and outreach plans to develop. It would also allow for policies to be targeted towards households most likely to be effected (see survey below). It was not possible to disaggregate MCMA residential energy use into the DF and EM or by income distribution, education or other characteristics, but qualitative assumptions allowed the model to be representative of area distinctions.

Guerin (2000) determined that energy consumption changes could be most effectively achieved by targeting the individual household. In a developing area like Mexico City, the differential between income and energy burdens is large. Those households with lower incomes would benefit from energy saving information for emissions and monetary reasons. For this reason, policies must be able to address distributional equity issues, accomplished more easily with improved household knowledge.

Model Inputs

Many inputs and assumptions are needed to supply data for the above equation, and to evaluate its evolution during the twenty-five year modeling period. Below are descriptions of each of the main model design parameters included for the residential sectors.

Energy Intensity

The Energy Intensity of end-uses and appliances represents the annual amount of energy consumed by an average household for a particular end use and fuel choice. This value is dependent on appliance efficiency, fuel energy content and the amount of time the appliance was used in the household. The unit energy consumption of a particular end-use may be high because the input power is high, because the equipment is used often, because more energy service is delivered or because the appliance itself is not efficient. The current per household energy consumption per appliance per household per year was used as a starting point, and then estimated to change during the 26-year period, dependent on future story characteristics. The way that this value changes over time is affected by five main factors:

- Household size (number of residents);
- Home size (area);
- Technological change of available products;
- Household income; and
- Energy Price.

Household size, represented by the number of household members, can affect energy consumption because it increases the need for more energy for such things as more fuel for cooking meals and more hot water for bathing and clothes washing. The size will affect different end-uses differently. For example, an additional household member will increase the amount of showers taken and clothes washed, but may not significantly increase the consumption of fuel for shared end-uses such as lighting.

The physical size of the home will increase energy consumption primarily through end-uses such as lighting and heating, because there is additional living space. Increased home size is also correlated with more possessions including energy consuming appliances.

Household appliances have gradually become more efficient over time. While Mexican appliances are slightly less energy efficient than those currently available United States appliances, the two markets follow a similar trend. The rate at which these improvements occur and the penetration of the improved appliances within the market and within residences will affect household energy consumption.

Household income will affect energy intensity for several reasons. First, households with higher incomes will not be restricted by income to conserve energy. Therefore, they will have a tendency to increase energy consumption by using existing appliances more and by purchasing additional appliances. Household income can also affect the physical size of the home. Often, the unit energy consumption in higher income households is likely to be greater because higher levels of energy services are delivered (Sheinbaum and Dutt, 1996). In some cases, lower income households could have less efficient appliances for affordability reasons, but this is not often the case because these same households are forced to conserve energy for financial reasons.

Energy intensity of appliances have been gathered by Oscar Vazquez at GDF for input to the BRUS II model[12]. These values were verified using data from Mexico City literature, appliance marketing literature and appliance efficiency standards[13]. They were assumed to be homogeneous in all of the MCMA because more specific information is not available at this time. Table 8 shows the values used in the model for 1996 energy intensities[14]. These values were then adjusted each year using the factors described above.

Table 8. 1996 Major Appliance Energy Intensities

Appliance	PJ/yr-hh	Electric Appliance	PJ/yr-hh
Cooking: FW	39.4	Air Conditioner	1,600
Cooking: LPG	13.1	Refrigerator	550
Cooking: NG	9.2	Water Pump	200
Cooking: Elec.	8.0	TV	160
Cooking: Solar	8.0	Clothes Washer	120
Water Heating: FW	17.3	Microwave	100
Water Heating: LPG	17.1	Fan	88
Water Heating: NG	13.2	Iron	70
Water Heating: Elec.	14.0	Computer	20
Water Heating: Solar	14.0	VCR	20
Drying: FW	10	Radio	10
Drying: LPG	10	Record Player	10
Drying: NG	10	Video Game	10
Drying: Elec.	10	Parabolic Antennae	10
Heating: FW	16.0	Sewing Machine	10
Heating: LPG	10.5	Blender	10
Heating: NG	10.5	Hand Mill	10
Heating: Elec.	9.5	Vacuum Machine	10
Heating: Solar	9.5	CD Player	10
Lighting: LPG	4.9		
Lighting: NG	2.0		
Lighting: Elec. (Incand.)	1.82		
Lighting: Elec. (CFL)	0.6		
Source, BRUS II; Sheinbaum, Martinez and Rodriguez, 1996			

[12] The Brundtland scenario model (BRUS) is a long-term simulation model for the energy demand and supply system, created for the Danish energy system and adapted for Mexico.
[13] For many appliances, these values were lower than those cited as U.S. annual unit consumption (Koomey, 1998), but were used because they were specific to Mexico.
[14] Efficiencies of 10 PJ/hh-yr are placeholders because actual values could not be located. However, sensitivity analyses described later show that this uncertainty is not significant.

Appliance and Fuel Saturation
To accurately represent energy consumption in households, an estimation of the number of households that have particular appliances and use particular fuels is essential. As mentioned above, increased household income can be linked to increased appliances purchases. More homes will be able to purchase convenience and entertainment appliances such as air conditioners and television sets, and homes may also have the luxury of owning multiple appliances, such as a television set for several rooms.

Appliance saturation values were taken from INEGI's ENIGH and the Mexico 2000 Census. The ENIGH is published every two years and data was available for 1982 and 1992-2000 (2000 is the most recent publication). Although the survey is national and the data is not aggregated in a way to be representative of the MCMA, data is can be aggregated by urban and rural categories and the urban data was assumed to be representative of the MCMA. For 1996, these values were validated using Census data, which is available at the municipality and delegation level. The ENIGH was also used for fuel saturation data. However, a flaw in the survey is that it does not differentiate between LPG and natural gas. This will become very important if fuel switching is determined to be an attractive air pollution reduction strategy. Current appliance and fuel saturation values were shown earlier in Chapter 5 in Figures 12 and 13.

Appliance Turnover
Appliance turnover will occur in households as appliances are replaced because they no longer function or are out of date (natural turnover) or because the household switches to a fuel that requires a new appliance. Estimates of turnover were based upon appliance expected lifetimes and warranties provided by the manufacturers and fuel switching estimates as described below. When possible, appliance manufacturers specific to the Mexican market were used. Table 9 below shows the average turnover rates used in the Residential Model. This average was then adjusted based on future story characteristics. For example, a future with less household income growth would decrease the turnover of appliances as households keep old appliances longer.

Table 9. Major Appliance Turnover Rates

Appliance	Turnover % per yr	Electric Appliance	Turnover % per yr
Cooking: FW	6	Air Conditioner	8
Cooking: LPG	6	Refrigerator	6
Cooking: NG	6	Water Pump	8
Cooking: Elec.	6	TV	8
Cooking: Solar	6	Clothes Washer	9
Water Heating: FW	8	Microwave	8
Water Heating: LPG	8	Fan	8
Water Heating: NG	8	Iron	8
Water Heating: Elec.	8	Computer	8
Water Heating: Solar	8	VCR	8
Drying: FW	6	Radio	8
Drying: LPG	6	Record Player	8
Drying: NG	6	Video Game	8
Drying: Elec.	6	Parabolic Antennae	8
Heating: FW	8	Sewing Machine	8
Heating: LPG	8	Blender	8
Heating: NG	8	Hand Mill	8
Heating: Elec.	8	Vacuum Machine	8
Heating: Solar	8	CD Player	8
Lighting: FW	100		
Lighting: LPG	50		
Lighting: NG	50		
Lighting: Elec. (Inc)	100		
Lighting: Elec. (CFL)	15		
Lighting: Solar	100		
Source: American Council for an Energy-Efficient Economy, 2002; Koomey, 1998			

Fuel Switching Inputs

Since the mid-1980's, MCMA households have switched from a ratio of about 90-10 for LPG-NG use in the home for cooking and water heating to essentially 100 percent use of LPG. Now, however, this trend seems to be reversing. Drivers of fuel switching, as modeled, include fuel prices, household income and service availability.

Energy price changes, if drastic enough, may cause households to switch fuels. This was one reason for the increased use of LPG historically. If desired, changing the fuel price by an increase in tax or a subsidy, is a policy option decision makers could consider to encourage switching to less polluting fuels, but the price change would have to be considerable to induce any significant switch. The CRE predicts that residential users will be able to reduce their gas bills by up to 41 percent[15] if they switch from LPG to NG (CRE, 1998).

[15] As modeled, this number was slightly lower.

Other future story characteristics will also affect household fuel preference and ability to switch to alternative fuels. These include household income, environmental awareness and unification between the U.S., DF and EM in terms of technology considerations and service availability.

The availability of fuel plays a strong role and predictor of fuel switching. As mentioned above, MCMA residents moving out of the city to the periphery may experience limited fuel selection. Another issue is whether the current trend of increasing natural gas delivery infrastructure will continue. There are two natural gas distributors in the MCMA, Mexigas and Metrogas, which have secured contracts from the city government to construct natural gas pipelines in the city. They currently have approximately 130,000 household contracts (three percent of the MCMA population) but these companies, the energy ministry and other government officials and citizens have expressed their anticipation of fast and steady market growth. Current contracts would serve 350,000 households (about seven percent of the MCMA population). The Energy Ministry expects the residential LPG share to drop to about 85 percent by 2010 as consumers switch to natural gas. However, such switching is limited by fuel and infrastructure availability – natural gas distributors only have existing contracts for much less than this amount (SE, 2001). Most residents in multi-unit houses are not given the option to continue with LPG, and are forced to switch to NG as it become available in their neighborhood. This eliminates the need of housing managers to supply multiple types of fuel.

For modeling purposes, fuel switching potential has been constrained by historical trends, existing contracts, and energy ministry predictions until 2010. Technology-related advances, such as the introduction of solar water heating, have also been incorporated. The Base Reference Case (described in more detail later) is characterized by about one-half percent of homes each year switching from more polluting to less polluting fuels. More aggressive options, described in more detail later, assume that a larger percent begin switching in 2003.

Emission Factor Inputs

Emission factors are obviously very important for calculation of residential sector air pollution. Emission rates of pollutants from different appliances can vary over several orders of magnitude. Variation can even occur within individual units of a single appliance model, due to many interrelated factors: fuel type; type of appliance; appliance operation, tuning and maintenance; ventilation; age; combustion efficiency; and amount of use.

Initially, U.S. Environmental Protection Agency AP-42 documentation was used to find emission factors for the model because it provided factors for all five criteria pollutants modeled: PM10, SO_2, NOx, CO and NMHC and for each fuel type modeled: wood, LPG and Natural gas. Wood combustion was listed as residential fireplaces in AP-42 (Table 1.9-1 and 1.9-2), residential LPG use was not included in AP-42 so factors for commercial LPG boilers were used (Table 1.5-1 and 1.5-2) and natural gas was represented in AP-42 by residential furnaces (Table 1.4-1 and 1.4-2). These emission factors were then compared with those in the BRUS II emissions model, the CAM Emission Inventory and the 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. There were few discrepancies, so the one considered most representative of Mexican conditions were used.

After comparison, AP-42 was not found to be representative of the Mexican environment in several circumstances. Because the composition of LPG in the United States is different than in Mexico, the LPG factors were replaced by emission factors from the BRUS II model. AP-42 factors for VOCs were used to represent NMHC factors because they were very close to those in the BRUS II model. For electricity, emission factors from several sources were used, compiled by another project member. It is expected that these emissions on a per unit output basis will be relatively stable; as electric generation grows, new capacity will be a mix of high efficiency NG based power generation units and/or coal units. The final emission factors used for fuel combustion in the residential model are shown in Table 10.

Table 10. Residential Model Fuel Combustion Emission Factors, tonne/PJ

Fuel	PM10	SO2	CO	NOx	NMHC
Solid Fuels	853.6	11.2	6,438.3	78.1	1,355.7
LPG	2.2	0.0	10.3	70.0	2.6
NG	0.1	0.3	17.2	40.3	4.8
Electricity	6.3	0.8	50.5	429.4	2.2
Source: CAM EI for LPG; EPA AP-42 for Solid Fuel; BRUS II for NG; Vijay for Electricity					

Emissions factors for non-fuel combustion sources were found in other resources. Emissions from LPG leakage were found in CAM's 1998 Emissions Inventory and are shown below in Table 11 and 12.

Table 11. Residential Model LPG Distribution and Storage Leakage-Related Annual Emission Factors

	tonne NMHC gas/tonne LPG
Distribution	4.48E-04
Storage	6.19E-03
Source: 1998 CAM Emission Inventory	

Table 12. Residential Model LPG Domestic Leakage-Related Annual Emission Factors

Accessories and Installations		Pilots & Ignitions		Unburned NMHC	
Tonne NMHC/installation		Tonne NMHC/equip.		Tonne NMHC/equip.	
Connections	2.07E-03	Stove pilots	1.02E-03	Stoves	5.42E-03
Picteles	1.97E-03	Water Heater pilots	1.57E-07	Water Heaters	2.33E-03
Regulators	1.09E-03	Stove ignition	2.24E-04		
Stationary	1.05E-03	Water Heater ignitions	1.57E-07		
Stoves	1.21E-04				
Heaters	1.21E-04				
Portable	3.03E-05				
Valves	2.42E-05				
Source: 1998 CAM Emission Inventory					

AP-42 included commercial and consumer solvent use emission factors (pound/yr non-methane VOC – NMVOC) for ten categories of solvents (Table 4.10-1). Another EPA document used in support of Emission Inventory development provided per capita consumer and commercial solvent hazardous air pollutant (HAP) emission factors in pound/yr/person for over thirty pollutants. It also provided consumer and commercial solvent VOC emission factors in lb VOC/person for eight product categories. These are shown below in Table 13.

Table 13. Residential Solvent Annual Emission Factors

Product Category	**Per Capita Emission Factor (pound VOC/person/yr)**
Personal Care Products	2.32
FIFRA-Regulated Products	1.78
Automotive Aftermarket Products	1.36
Coatings and Related Products	0.95
Household Products	0.79
Adhesives and Sealants	0.57
Miscellaneous Products	0.07
Total for all Consumer and Commercial Products	7.84 (9.2)
Source: EPA 1996, Consumer and Commercial Solvent Use, Final Report, page 5.4-3 Note: Value in (parentheses) is AP-42 per capita emission factor	

Additionally, a report by a United Nations Development Programme (UNDP) working group (Gruman) estimated VOC and NMVOC emissions from the use of solvents in Brazil. Nine commercial sub-sectors were considered, as well as domestic use. Domestic use included the following product categories: cosmetics and toiletries, household products, buildings, and car care products. They stated that a simple methodology is to use the average emission in the UK, Canada and US. This average was 2,566 gram VOC/person/year (5.7 pound VOC/person/yr). Converting this to a developing country, Brazil in their case and Mexico in ours, would result in an overestimation because of the smaller and overall less affluent economically active population. By adjusting the average factor according to the different levels of income in Brazil, the overestimation is dampened and the resulting emission factor would be approximately one-tenth of the US. Similar corrections were performed for our model – the emission factor was estimated to be approximately one-third of the U.S. To improve this estimation, the report authors recommend a field survey of the manufacturers of domestic solvents.

Elasticity Inputs
The price and income fuel consumption elasticities were important assumptions for modeling the residential sector emissions. Sheinbaum and Dutt (1996) and Sheinbaum, Martinez and Rodriguez (1996) attempted to estimate residential fuel consumption elasticities for income, price and household size for the period 1970-1990. They found fuel price has been inelastic with respect to household energy consumption, and that household size followed by income were the most important factors. Another finding was that, even as aggregate GDP has been rising, average consumption per household stays constant because of the large number of low-income new entrants. Results of the U.S. RECS have shown that, similarly, the factors that most influence home energy use are geographic location, socioeconomics and household income (EIA, 2002). Considering only commercial energy, which would exclude fuel-wood, household size was shown to be the most important variable, followed by income. Price was shown to be inelastic with respect to household-energy demand, making any policy to increase fuel prices to induce conservation of fuel switching less successful without a dramatic increase. This relative order of elasticities was used in the model.

<u>Reference Cases</u>
The Integrated Scenario Analysis team has chosen to create three reference cases for modeling each sector; each can be simply labeled as business as usual. They represent the state of the residential sector if patterns of growth and activities continue following historical trends, current conditions and established MCMA air quality improvement plans. The three different reference cases developed are: the Base Case, the Ideal PROAIRE Case and the MIT PROAIRE Case. These were modeled using the trends described above. All emission reduction strategies from official air quality programs are labeled "measures." Any additional or altered strategies are labeled "options." Measure and options were modeled as described below.

Base Case
The Base Case Reference Case is business as usual, including 1995-2000 PROAIRE measures that have already been implemented. Business as usual includes current patterns of fuel switching, appliances purchases and other consumption trends. No major residential options were included in the 1995-2000 PROAIRE, so none are modeled in the base case.

Ideal PROAIRE
The Ideal PROAIRE Reference Case is built upon the base case, and also includes 2002-2010 PROAIRE draft measures as designed. These measures are scheduled for

implementation before 2010, but this implementation has not yet begun. The Ideal PROAIRE case models the residential sector as if all options affecting this sector will be implemented as planned in terms of scope, schedule and cost. There is only one measure in the 2002-2010 PROAIRE that specifically targets the residential sector. This measure[16] is the creation of a program to reduce LPG leakage from one million household cooking stoves by 2010. The program is scheduled to begin in 2002 and was estimated to cost $50 million. Additional details of this option are shown in Table 15 below.

MIT PROAIRE

As we are entering 2003, it is probable that the 2002-2010 PROAIRE measures will not be implemented as planned in terms of timing and scope. The MIT PROAIRE Reference Case includes all PROAIRE measures (only one for the residential sector) but models them in a way that is more likely to occur and be feasible. For the residential measure, this incorporates is a delayed program start date, a reduced goal of emissions reduction per home, and an extension of the program to 2025, our final modeling year.

Additional Emission Reduction Options

The residential sector has been essentially left out of the latest PROAIRE. However, for the exposure reasons described earlier, it should be considered. Additionally, as the cost analysis may show, emission reduction options may be more cost-effective and reduce greater amounts of direct exposure than other options. For these reasons, several additional emission reduction options have been evaluated, in addition to the PROAIRE measure. They were modeled in different degrees – from modest to aggressive – and with a range of deployment schedules. These option sets and ways they were modeled are listed in Table 14 and described below.

[16] Services Measure #4. Emissions Reduction for LPG Leakage in Domestic MCMA Installations

Table 14. Residential Model Option Sets

Option Set	Option	No. of Options
Fuel Switch Option Sets		
Cooking	Current Trend Switch to Natural Gas Switch to Electricity Switch to Natural Gas and Electricity	4
Water Heating	Current Trend Switch to Natural Gas Switch to Electricity Switch to Natural Gas and Electricity Switch to Solar	5
Clothes Drying	Current Trend	1
Heating	Current Trend	1
Lighting	Current Trend	1
Electric Efficiency Option Sets		
Lighting	Current Trend Switch to CFLs	2
Appliances	Current Trend Refrigerators TV Air Conditioner Clothes Washer All of the Above	6
Fugitive Emission Option Sets		
LPG Leakage	Current Trend (Base Case) Ideal PROAIRE MIT Realistic PROAIRE	3
Solvent Use	Current Trend	1
Distribution Option Sets		
Natural Gas	Current Trend	1
LPG	Current Trend Leakage Reduction	2
Possible Option Combinations = 4*5*1*1*1*2*6*3*1*1*2 = **1,440 strategies**		

However, all of the 1,440 possible option combinations (strategies) were not analyzed. Some were discarded because certain options are incompatible with others. For example, households switching to natural gas for water heating will not keep LPG as their cooking fuel; they will also switch to natural gas for cooking. Each of these option sets is described below.

Fuel Switching Option Set

Households can switch from any fuel to any other fuel, but some switches are more likely. It is improbable that a home currently using fuel wood would have the financial means and opportunity to switch to solar, for example. Additionally, once a building has been retrofitted for natural gas, households are unlikely to switch back to LPG. The general progression of switching is from fuel wood to natural gas to electricity to solar, but some variation is possible and the prevalence may differ by end-use. These considerations have been incorporated into the model – options include switching from FW to LPG, NG, electricity or solar, from LPG to NG, electricity or solar, from NG to electricity or solar, and from electricity to solar[17], with the more likely switches occurring more often.

The fuel switching options assume that a percentage of homes will switch from current fuel choices to the natural gas, electricity or solar each year for cooking and/or water heating. Options that promote fuel switching increase the annual percentage from the base case value of one-half percent to as high as ten percent of homes using a particular fuel per year; this value is dependent upon the future story factors mentioned above. The option is modeled as a program that begins in 2003 and continues until 2025.

Some fuel switching, such as to natural gas, will necessitate infrastructure improvements and/or expansion. Within the housing unit, switching to natural gas requires a new connection and stove retrofit. Other switches require purchase of a new appliance. Other costs include the cost of constructing new fuel lines, which may be transferred to consumers through fuel prices. These infrastructure, equipment, connection and retrofit costs are included in the residential model.

Household fuel switching from fuel wood should be a top priority because of the large emissions, even if the number of household using this fuel is small (less than one percent). Some fuel switches, such as this one, would require the purchase of a new appliance. Because the average cook stove currently costs between $100 and $500, this desire conflicts with the financial ability of low-income homes that typically chose fuel wood as an energy source. Additionally, fuel wood will remain an attractive fuel because it can be free. Fuel wood scarcity, such as in suburban areas, may encourage a switch away from this fuel. In low-income areas using fuel wood, more than one household usually shares stove setups. This situation could continue with new stoves. Overcoming cultural barriers to switching to new fuels could be accomplished by involving the local residents in stove design and education.

Lighting Efficiency Option Set

The lighting efficiency option was modeled by assuming that a certain number of households would switch from incandescent bulbs to CFLs and would continue to use CFLs indefinitely. The original option modeled called for 100,000 homes per year switch during each year from 2004-2025. A more aggressive option of 280,000 homes per year was also modeled. A complete switch to CLF lighting results in a decrease of lighting electricity consumption by roughly 60 percent per household, but would initially require an increased purchase cost for the new, relatively more expensive bulbs. A program established to perform such a switch would also require personnel for performing an energy audit and/or supplying the new bulbs. The model includes these labor, program and equipment costs

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[17] Solar is only considered for water heating.

Appliance Efficiency Option Set
As stated above, appliance efficiency (energy intensity) values were found in the BRUS II model and other secondary sources. Efficiency for all appliances was assumed to improve by a certain percentage per year, based on historical Mexican industry improvements. Electric appliances are assumed to improve at a smoother and more continuous rate than appliances using other fuels, but for the model all autonomous technical improvements are assumed to be linear. One characteristic of the future stories is the degree to which technology improvements are made, so this baseline is adjusted accordingly. Reduced electricity consumption reduces fuel-combustion related emissions. An important reduction, while not included in this analysis, is a drop in greenhouse gas emissions. An additional benefit is the reduced dependence on electricity generation outside of the valley. Any reduction in electricity consumption also increases household energy monetary savings.

Energy efficiency opportunities have not been taken advantage of in Mexico (Friedmann and Sheinbaum, 1998). Current efficiency standards are well below those in the U.S., where large electricity savings have resulted from more stringent regulations and the creation of voluntary programs (Geller, 2001; Koomey, 1998). An emission reduction option, targeted to appliance efficiency, was modeled for four major electric appliances: refrigerators, televisions, air conditioners and washing machines. These appliances were selected because they have large, or growing, saturations in the MCMA and because each is a larger energy consumer. Additionally, the U.S. Environmental Protection Agency has developed target efficiency levels for each of these appliances within their Energy Star program[18]. The modeled control option consists of a new appliance efficiency standard being put in effect in 2005 that matches the Energy Star level.[19] These Energy Star levels are between 20 and 30 percent more stringent than the current household average efficiencies, depending on the appliance type. It was assumed that, at the time the standard is put into place, all new appliances purchased (for new homes and for natural turnover) would meet that standard. After the year of the new standard, technology improvements would continue at the same historic rate.

Leakage Reduction Option Set
Leakage reduction was modeled by targeting specific points of leakage. The Ideal PROAIRE measure was modeled as described – a percentage reduction in total emissions from a certain number of households. The MIT PROAIRE was modeled as targeting and eliminating leakage from stove pilots from a certain number of households. Table 15 and

[18] U.S. EPA Energy Star program, introduced in 1992, provides information on energy efficient options for homes and businesses – labeling of efficient products, information on energy saving practices, etc. – to reduce carbon dioxide emissions. The label is produced through a partnership with the U.S. Department of Energy.

[19] The Energy Star program is voluntary for manufacturers, as the levels required for labeling are more stringent than those mandated by the National Appliance Energy Conservation Act (NAECA) of 1987. NAECA standards are also more stringent than Mexican standards in some cases. Proposed mandatory U.S. standards could reduce efficiency of certain appliances by as much as 45 percent in five years. Energy consumption by U.S. household appliances has decreased by about 40 percent since the 1970s (Swatkowski, 1999).

Figure 17 below show how these options were modeled (Figure 17 shows the projected number of households using LPG under the Changing Climate future story). Because this was the only residential option included in the PROAIRE, the Base Case and these two options form the three residential reference cases. The model results described in Chapter 8 show that these two options only decrease the rate of leakage, but do not decrease total leakage from current levels (due to continued increase in the number and income of MCMA households). Therefore, more aggressive options targeting more points of leakage were also considered. The more aggressive option modeled was scheduled to begin in one year later, targeted more homes per year, and had reduction per home equal to PROAIRE plans.

Table 15. Residential LPG Leakage Reduction Options, As Modeled

	Base Case	Ideal PROAIRE	MIT PROAIRE	Aggressive
Inter-institutional group formed	-	2002	-	-
Campaign period	-	2002-2010	2003-2025	2004-2025
Cost	-	$50 Million	Depends on Future Story	Depends on Future Story
# of HH reached/yr	-	111,111	100,000	180,000
# of HH reached by 2010	-	1 Million	800,000	1,400,000
# of HH reached by 2025	-	1 Million	2.3 Million	4.1 Million
Repair Method	-	Unspecified	Pilot repair	Unspecified
% leakage reduction per HH reached by program	0%	40%	6%	40%

Note: HH = households

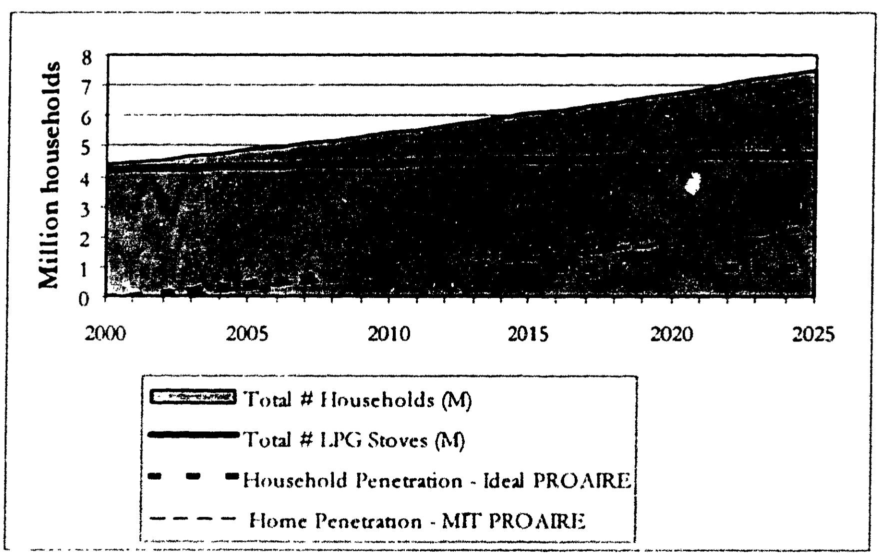

Figure 17. Household Penetration under LPG Leakage Reduction Options

Solvent Consumption Option Set
Solvent consumption, although absent from the emissions inventory, is an important source of residential hydrocarbon emissions and a potential point for emissions reductions. Within the U.S., several solvent substitutes that have fewer and less harmful emissions are commercially available. Two strategies were considered but not yet modeled; they include: the use of solvent substitutes and the improved use of solvents so that less emissions are created.

Future Stories
Using the above equation, we can estimate the energy consumption and related emissions from the residential sector for historical years. However, to estimate these same values for future years, assumptions must be made on the characteristics of the future: population size, household size and income, energy prices, technological capabilities, and more.

If this model is to be used to evaluate emissions reduction options, we must consider that the future will not evolve in only one way. This evolution may affect the preference of one option over another, based on fuel consumption and emissions evolution as well as costs. By evaluating options across several possible futures, we can select strategies that are robust, which will be useful to educate decision makers. Agreements and alternative courses of action should anticipate various futures (Susskind, 1994). Modeling the residential sector emissions within these three future stories recognizes the uncertainty surrounding these characteristics and can test for sensitivity of the potential emissions reduction options.

Each of the emission reduction options considered contains both parameters that are independent of and dependent upon the future story. For example, the LPG reduction option is currently modeled as a set number of homes per year that are repaired. However, the fuel switching options are modeled as a percentage of homes that switch to an alternative fuel per year, depending on future story drivers including household size, income and qualitative variables.

There are both qualitative and quantitative components to the future stories. A general description of the conditions and trends of each has been constructed, which includes such details as the direction and rate of urban sprawl, harmonization of technology, the level of environmental awareness in cities and the institutional capacity for change. Many of the drivers described above are provided quantitatively in the future stories, such as population, household size, household income and fuel prices.

Early observations show that future stories have a significant impact on the relative performance of residential emission reduction options, as indicated earlier. Futures characterized by households with larger size and lower income will be less likely to switch to an alternative fuel. While switching may not be fuel cost prohibitive, and many times result in cost savings, installations fees and perceived time burdens may be too high. Future stories may also affect the likelihood of infrastructure investment. Growth in the number of households can also overwhelm any per household reductions. Additionally, household size and income dynamics result in changes in fuel and appliance purchases and consumption.

Divided City

A Divided City future story is characterized by slow national GDP and even slower per capita GDP growth per year but increasing income inequalities through the MCMA. There is also urban instability and violence and a highly segregated urban development. This division is also illustrated through a high level of political conflict between the State of Mexico and the Federal District, preventing metropolitan level governance. Such inequalities limit the harmonization of emissions reduction measures and the financial ability of the growing poor population to participate in any programs that increase their household expenditures. Urban sprawl and population growth is greatest through this future story, placing more households outside of existing fuel supply infrastructure. Another characteristic is the inability of government to integrate public participation into policymaking process, placing residential exposure at a lower priority. Enforcement of laws and program investments was also low in this future story, decreasing the penetration and effectiveness of government programs and ability to invest in fuel supply systems. A high population growth increases number of consuming households.

Changing Climate

The Changing Climate future story shows Mexico as an active participant in the international climate agenda. Public and media attention is focused on the growing evidence of local impacts of global climate change. This increased awareness can be expected to result in increased consumer switches to less polluting fuels and more efficient appliances. Technology development is advanced and cities participate in rapid transfer of "best practices," making new appliance purchases even more beneficial in terms of energy consumption reduction. Decreasing income inequality promotes increased equity in household ability to participate in government energy-savings programs and include environmental considerations in household decisions. Metropolitan governance further enables harmonization of efforts across the MCMA. A drop in household size reduces per household consumption values. High levels of government investment and enforcement increase program effectiveness and energy choices for consumers.

Growth Unbound

The Growth Unbound future story consists of low to moderate population growth within an increasingly decentralized city, straining fuel supply infrastructure. High-income growth increases per household consumption; this is exacerbated by conditions of low public participation and awareness of environmental impacts. Urban sprawl occurs, but not at the level of the Divided City future story. Technologies continue to lag behind those of the U.S., preventing significant improvements in energy efficiency of appliances. Despite high household income growth and financial ability to switch fuels, government investment and interest in environmental issues is low, preventing spread of supply infrastructure.

Some of the key residential drivers contained in the three future stories developed are highlighted in Table 16 below.

Table 16. Primary Future Story Residential Drivers

	A Divided City	A Changing Climate	Growth Unbound
Population	• Pop. increases 1.8% per year • # HH increase 60% during 26-yr period	• Pop. increases 1.6% per year • # HH increase 72% during 26-yr period	• Pop. increases 0.9% per year • # HH increase 66% during 26-yr period
HH Income	• Increases 1.4% per year • Growing income inequality	• Increases 1.9% per year • Shrinking income inequality	• Increases 4.4% per year • Continued income inequality
Technology	• Long lag behind US	• Convergence with U.S.	• Rapid turnover but lag behind U.S.
Urban Form	• High urban sprawl – area grows 4.2% per year; density drops 1.2% per year • HH size drops 10% by 2025	• Densification – area grows 1.1% per year; density increases 0.4% per year • HH size drops 18%y by 2025	• Urban sprawl – area grows 2.3% per year; density drops 0.9% per year • HH size drops 26% by 2025
Politics	• Party fragmentation • Unstable	• High investment and enforcement • Metropolitan governance	• Low government intervention
Environment	• Low priority	• Local awareness	• Not addressed

To illustrate the effect of the future stories, Figure 18 shows the percentage of households in each of three categories: fast; medium; and slow. The categories represent the speed at which households implement make changes such as switching to alternative fuels. For example, in the Changing Climate future story, households are able quickly switch to alternative fuels because of high and equitable household incomes and government investments. In the Divided City future story, in which there is significant income disparity, most household are either in the slow or fast categories. In the Growth Unbound future story, incomes are high and more uniform, but there is less environmental concern, so most households switch at a slow or medium speed. Additional effects of the future story characteristics are illustrated in the next chapter.

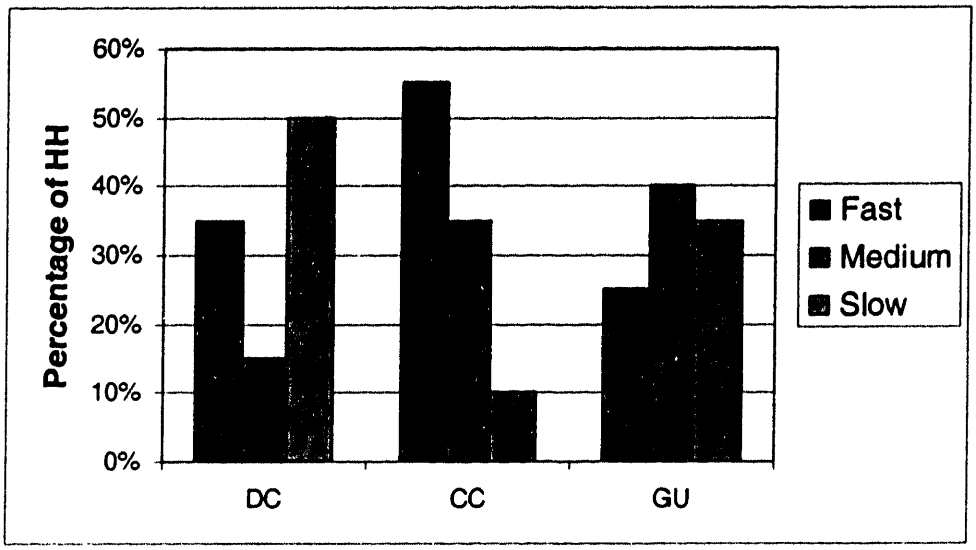

Figure 18. Future Story Effect on Speed of Household Fuel Switching

Scenario Construction

Each of the above options can be modeled individually, building upon any of the reference cases. However, realistic policies may utilize a combination of several options in order to share program personnel costs. For this reason, the options were modeled in bundles, of all possible combinations of options and across all three future stories. An option/measure bundle is labeled a "strategy." Together, the combination of a strategy and a future story is labeled a "scenario." Therefore, all possible combinations of the 1,440 strategies described above in Table 14 and the three future stories result in 4,320 scenarios.

Costs

To conduct a trade-off analysis, a second characteristic must be compared to emissions from the residential sector. The first, and primary, characteristic considered was cost. Each sector-specific model must use the same costing structure, so that these costs will be additive and can be used in conjunction with the additive emissions projections. Additionally, the costs must include all sector costs, not only option costs, so that cost comparisons can be made and the significance of increased costs due to emissions reduction options are shown relative to the business as usual residential costs. In this way, a very large option cost will not be dismissed because it is not financially feasible if this cost is only a small percentage of the actual total sector cost.

The costs included for the residential sector are capital costs, variable costs and air quality program costs. Each is described below. Each future story is associated with borrowing rates (for the residential model, assumed applicable only with respect to infrastructure investments), fuel prices, interest rates and discount rates. Trade-off comparisons are made between cumulative 2000-2025 emissions and net present value (NPV) in 2000 of sector costs.

Capitals costs include all direct purchases. For the residential sector, this includes appliance purchases necessitated by natural turnover and fuel switching. This would also include infrastructure costs, such as the construction of a new Natural Gas pipeline, that occur because of residential activity. If, however, the cost of distribution infrastructure is a transfer costs that is passed on to consumers through an increase in energy prices, it must not be double counted.

Capital costs were available from local manufacturers and fuel distributors. Estimates of these costs in the future were calculated using future story inflation rates, technological improvements, and estimates of future supply/demand relationships.

Variable costs are those costs that are a function of sector activity. For the residential sector, this includes fuel costs. Like capital costs, variable costs were available from local manufacturers and fuel distributors. Estimates of these costs in the future were calculated using future story inflation rates, technological improvements, and estimates of future supply/demand relationships.

Air Quality Program costs are any other administrative costs associated with the emissions reduction options. This may include the establishment of a governmental office to oversee LPG cook stove repairs and any labor, travel and office-related expenses resulting from the option. It also includes such expenditures as those for labor for employees sent to homes to retrofit appliances for new fuels, or to perform an energy audit and switch lighting from incandescent bulbs to compact fluorescent lighting.

Program costs are very uncertain and this uncertainty is noted when evaluating the cost of measures and options.

Model Output

The model has been constructed to produce information on dozens of attributes, covering fuel consumption, emissions, costs and other categories. This enables comparison across several points of interest. Each attribute can be evaluated on an annual basis and as cumulative values during the 26-year modeling period. Table 17 highlights the primary attributes used for analysis of the residential emissions reduction strategies. The most important and interesting are described in the next chapter.

Table 17. Primary Residential Sector Modeled Attributes

Household Attributes	
Per Household fuel consumption (PJ) Per Household fuel expenditures ($) Per Household equipment expenditures ($) Fuel Saturation (%) Appliance Saturation (%) Number of Households Switching Fuel	All of these have been modeled for new and existing households. Per household items reflect individual energy consumption patterns and cost burden. Saturation and switching values reflect choice patterns.
Fuel Consumption Attributes	
Annual consumption by fuel type (PJ) Cumulative consumption by fuel type: 2000-2010 (PJ) Cumulative consumption by fuel type: 2000-2025 (PJ) Annual consumption by end-use (PJ) Cumulative consumption by end use: 2000-2010 (PJ) Cumulative consumption by end use: 2000-2025 (PJ)	Fuel consumption attributes reflect fuel choice and consumption behavior. End-use values demonstrate efficiency of appliances. Sector fuel consumption can be compared to per household consumption to show the effect of increased MCMA population versus individual household behavior.
Emissions Attributes	
Annual emissions by pollutant (tonne) Cumulative emissions by pollutant: 2000-2010 (tonne) Cumulative emissions by pollutant: 2000-2025 (tonne)	Emissions attributes show produced pollution and can be used with fuel consumption patterns to reflect energy efficiency.
Cost Attributes	
Annual Capital Costs ($) Cumulative capital costs: 2000-2010 ($) Cumulative capital costs: 2000-2025 ($) Annual Variable Costs ($) Cumulative variable costs: 2000-2010 ($) Cumulative variable costs: 2000-2025 ($) Annual Air Quality Program Costs ($) Cumulative AQP costs: 2000-2010 ($) Cumulative AQP costs: 2000-2025 ($)	Capital and variable costs have different levels of transparency and feasibility for change at a household level. It is important to be specific about who is paying these costs; household behavior will be affected by the level of burden they must assume.

CHAPTER 8. MODEL FINDINGS

This Chapter presents the results of the residential model for the options and future stories described above in Chapter 7. First is a summary of the reference cases, followed by expected outcomes if the additional options are implemented. Because there is only one residential in PROAIRE, and this measure affects only fuel leakage and not consumption, the Base Case is the only Reference Case presented. Results are provided as trajectories during the 26-year period and as tradeoffs using the attributes included in the model.

When conducting the analysis, it was important to determine the sensitivity of the model for several reasons. First, many of the data sources are incomplete and uncertain, so we must determine the affect of this data and related assumptions on the modeling results. Also, option formulation, such as deployment schedule and assumed impact, is ultimately assumed based on experts and participants in the program. This formulation will be very dependent on future government regimes, urban development and other factors. Additionally, while a certain option may, at first, appear to be unsuccessful because of poor reduction achieved or high cost, altering the option characteristics, elasticities and other inputs may affect option preference. Even with these uncertainties, however, the model is useful for evaluating general trends and residential sector dynamics. If the model is especially sensitive to a certain variable, this knowledge can help direct the focus of future research efforts to remove such uncertainties and improve our knowledge base for designing appropriate emissions reduction policies. For these reasons, several different combinations of options and several different formulations of options were evaluated, as discussed below.

Base Case Model Results

Before evaluating emissions reduction options, a good understanding of the residential sector can be gained by modeling the base case under the three future stories for the 26-year modeling period. This can be done by evaluating projections during this period, to see how attributes and emissions evolve. We can then add to our analysis the other two reference cases and the additional emissions reduction options modeled, and evaluate the effect of these options on these projections, and within a tradeoff analysis by comparing emissions to costs.

Base Case Projections

The first step of the modeling process is to evaluate the trajectories of residential fuel consumption and other emissions generating activities.

Base Case Fuel Consumption

We can first evaluate estimations of fuel consumption patterns for the 2000-2025 period. As the population and average household income is expected to continue to increase, we can expect an undeniable continued increase in fuel consumption. Small amounts of fuel switching will change the relative share of each fuel, but the general pattern of fuel consumption is as shown in Figure 19. The Base Case is the only reference case shown

for fuel consumption, because the other reference cases only include an option to reduce LPG leakage, which does not significantly affect overall fuel consumption.

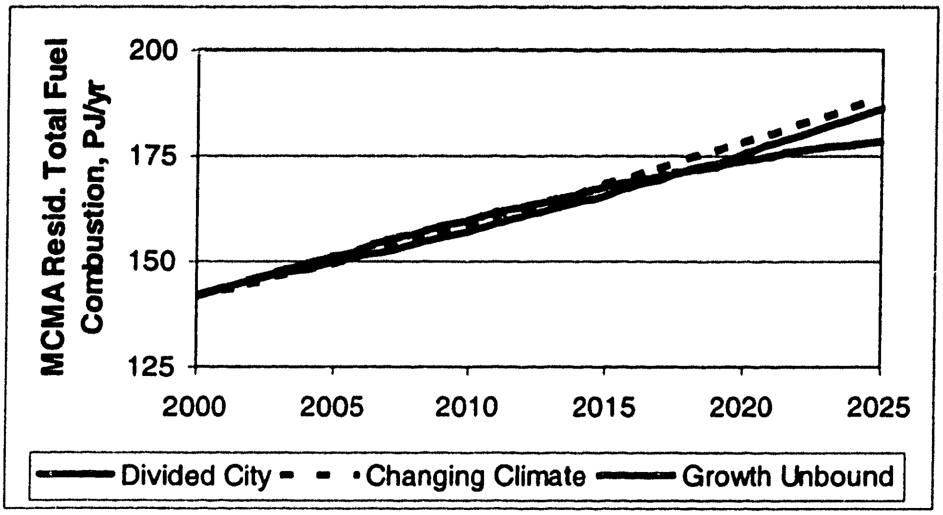

Figure 19. Total Base Case MCMA Residential Fuel Combustion by 3 Future Stories, As Modeled 2000-2025

Total annual MCMA residential fuel consumption could increase from current levels (about 140 PJ) by 26-33 percent by 2025, depending on the future story, primarily due to population and income growth. As shown, income growth in the Growth Unbound future story causes energy consumption to rise, but the population growth expected in the other two future stories is stronger and causes more long-term increases in fuel consumption. On a household basis, fuel consumption actually decreases by about 20 percent due to improvements in technology and decreases in household size, despite increases in household income.

The current residential fuel saturation shows a strong preference for LPG for non-electric end uses. Under the reference cases, this preference continues but 7-15 percent of homes, depending on the future story, will switch from LPG to other fuels as the necessary infrastructure and services become available; most of this switching is to NG. Figure 20 shows this trend for the Changing Climate future story, in which NG changes from a three percent to a 15 percent share of residential energy demand during the 26 years.

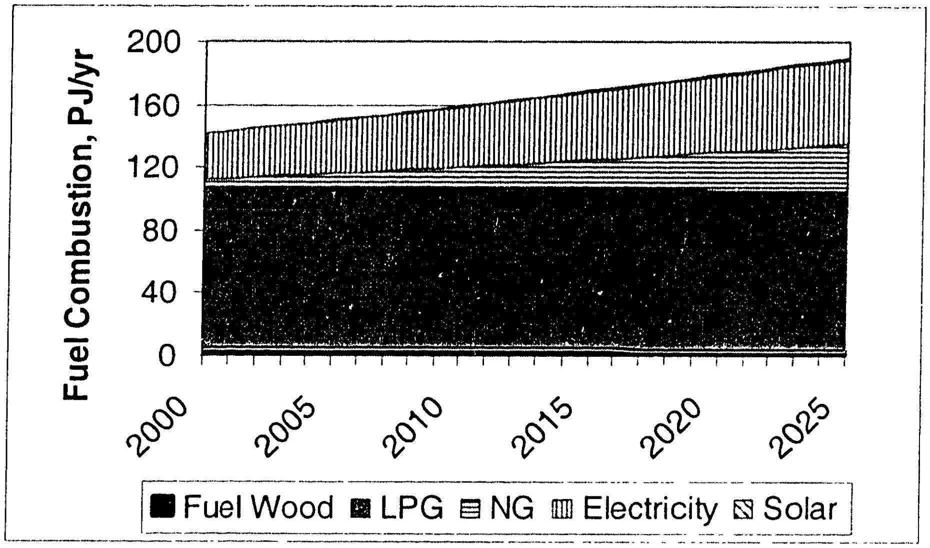

Figure 20. Base Case MCMA Residential Fuel Combustion – Changing Climate Future Story, 2000-2025 As Modeled

Growth in fuel consumption (only combustion is shown in Figure 19 because leakage is excluded) occurs primarily through an increase in NG use. Because the switch from LPG to NG is the most likely switch to occur, Figure 21 shows how this switch is affected by the future story characteristics. It seems that the future stories do not have much of an effect, because only minor changes are shown, even after 26 years. However, a change of only one percent represents over 40,000 households. So, the Growth Unbound Future Story shows that about two percent (about 80,000) fewer households have switched to NG by 2025. Later figures show that these effects are significantly enhanced when emissions reductions options are put into place.

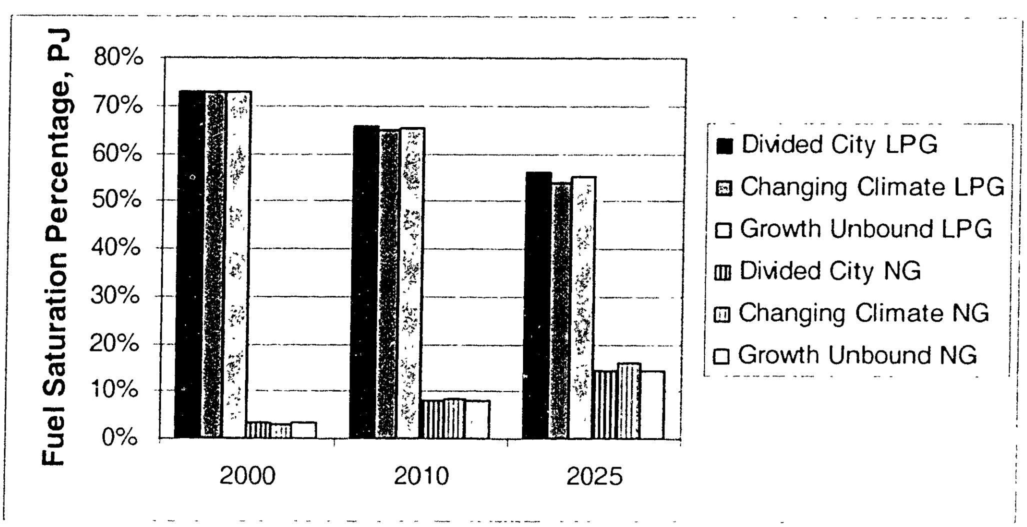

Figure 21. Base Case Residential Fuel Saturation Trends by 3 Future Stories, As Modeled, 2000-2025

From these three figures, we can see that the future story characteristics, without even applying any emissions reduction options, affect the residential profile. A larger number of households increase the fuel consumption of the residential sector. It also increases infrastructure needs and the size requirements of emissions reduction programs. On a household basis, income, size and equipment technology are also strong fuel consumption drivers, for reasons described earlier. Future stories with income disparity causes inequities in household ability to switch to alternative fuels and purchase new appliances, reducing the effectiveness of fuel switching and efficiency programs. Technology harmonization with the U.S. is an important factor affecting energy efficiency.

Base Case Emissions

Using the estimate of fuel consumption and estimations of non-fuel combustion related emissions, predictions of Base Case residential emissions can be generated for each of the three future stories. Similar to fuel combustion figure shown above, only the Base Case is shown for all emissions other than NMHC, because the PROAIRE reference case option only affects LPG leakage and, therefore, NMHC emissions. Figures 22-24 show PM10, NOx and NMHC emissions for each of the three future stories.

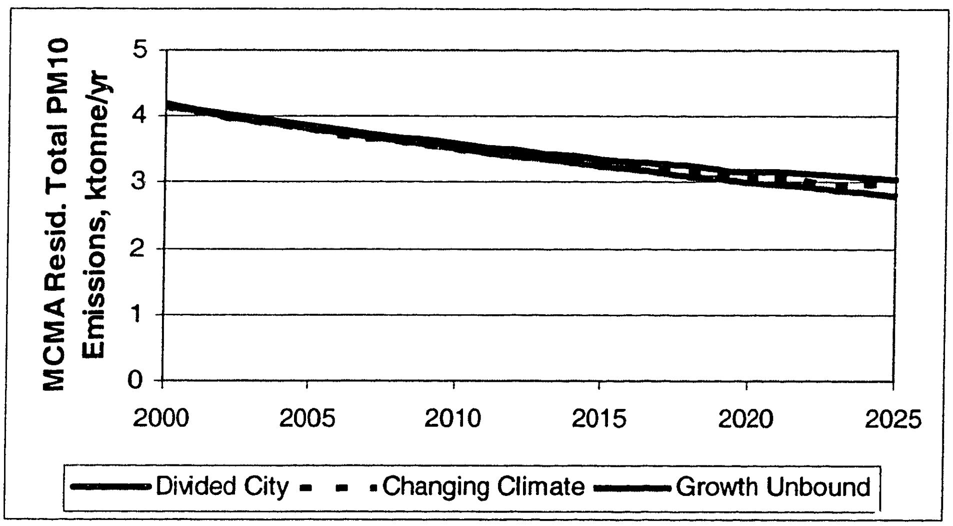

Figure 22. Total MCMA Base Case PM10 Emissions by 3 Future Stories, As Modeled, 2000-2025

Almost all of the residential PM emissions are from fuel wood consumption. The emissions reductions shown here (27-33 percent) are the result of the a decrease in the small amount of the use this fuel, as expected from income, technology and fuel availability changes in each of the future stories. Small differences are primarily due to population differences in the future stories.

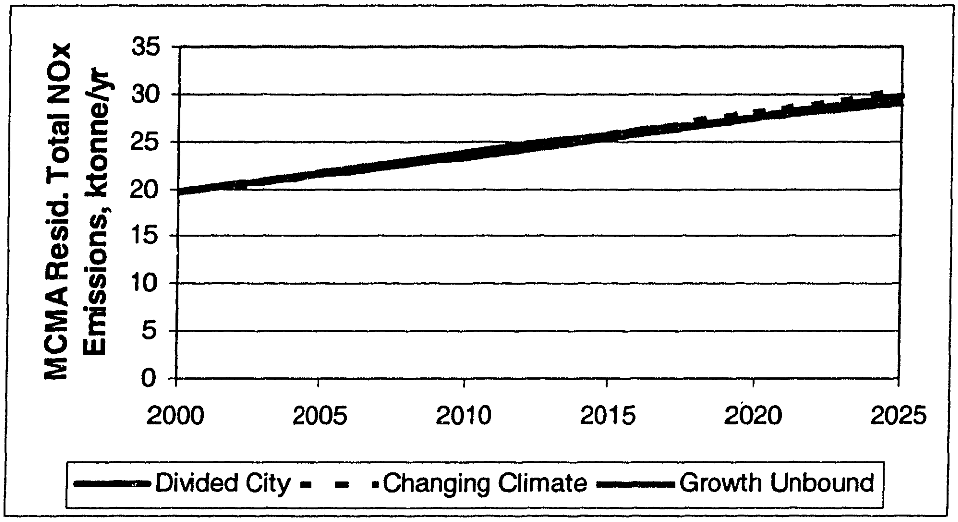

Figure 23. Total MCMA Base Case NOx Emissions by 3 Future Stories, As Modeled, 2000-2025

Similar to the PM10 emissions, most of the residential NOx emissions are from combustion of one type of fuel – electricity, which does not affect household exposure since it occurs at the power plant. Because most of the naturally occurring fuel switching occurs between LPG and NG, and does not involve electricity, the pattern of NOx emissions does not vary much between (within four percent) future stories. It should be noted, though, that a four percent change in 2025 is still a difference of over 5,000 tonnes during the 26-year period.

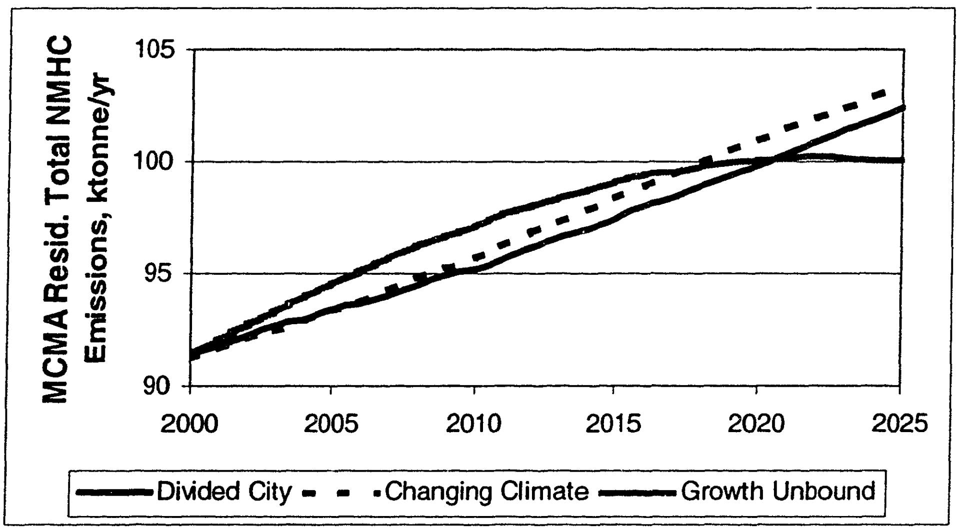

Figure 24. Total MCMA Base Case NMHC Emissions by 3 Future Stories, As Modeled, 2000-2025

Residential NMHC emissions continue to increase as population increases. The increase declines in the Growth Unbound future story because of slower population growth and a drop in household size, decreasing per capita solvent emissions and number of households with fuel leaks. In 2025, the difference is about four percent.

As shown above, most emissions will continue to increase because of their direct correlation with fuel consumption increases. Besides PM10, the only other decrease is CO, again because of a switch away from the small amount of fuel wood being used. Non-fuel consumption related emissions (leakage and solvent consumption) also increase as household numbers and size increase. In 2025, emissions are highest in the changing climate, primarily due to high number of households, higher household incomes and lower income disparities.

Additional Option Model Results

Beyond the three reference cases, the hundreds of residential emission reduction strategies were modeled for each of the three future stories. Realistic option parameters as well as very aggressive options that would be necessary to obtain a significant reduction (for example, reducing annual emissions to one-third to one-half of current levels) of residential emissions have been modeled. The key option sets and their effect on the projections shown above are presented here. They are shown individually, and not aggregated, because most of the options are targeted to particular fuels or pollutants. Then, these options sets are evaluating using a tradeoff methodology by relating emissions attributes to others, primarily costs.

Option Projections

Many of the emission reduction options modeled are directly targeted towards a specific fuel or a specific emission. As such, the emission reduction associated with them is easy to predict, and depends mostly on the degree of aggression assumed. For example, the option targeting a reduction of LPG leakage from homes will reduce NMHC emissions at the exact rate of leakage reduction assumed. The scenario analysis adds value to these basic predictions because it can combine these results with the possible futures we have developed as future stories and can evaluate the combinatorial effect of multiple options simultaneously. This allows a determination of which options will be most effective under which conditions. For many of these, results are only shown for one future story – the effects of other futures stories can be predicted using the dynamics described above. If unexpected effects were found they will be noted.

Fuel Switching Option Set

The first option set modeled is switching to less polluting fuels for cooking and water heating. Figures 25 and 26 below show the fuel saturation and resulting fuel consumption assumed for each of the options modeled for cooking. Cooking is shown because its saturation in households is practically 100 percent. Similar trends result for water heating, but the rate is lower because of a smaller initial water heater saturation and the inability of households living in apartments or other combined living units to make the decision to switch on their own.

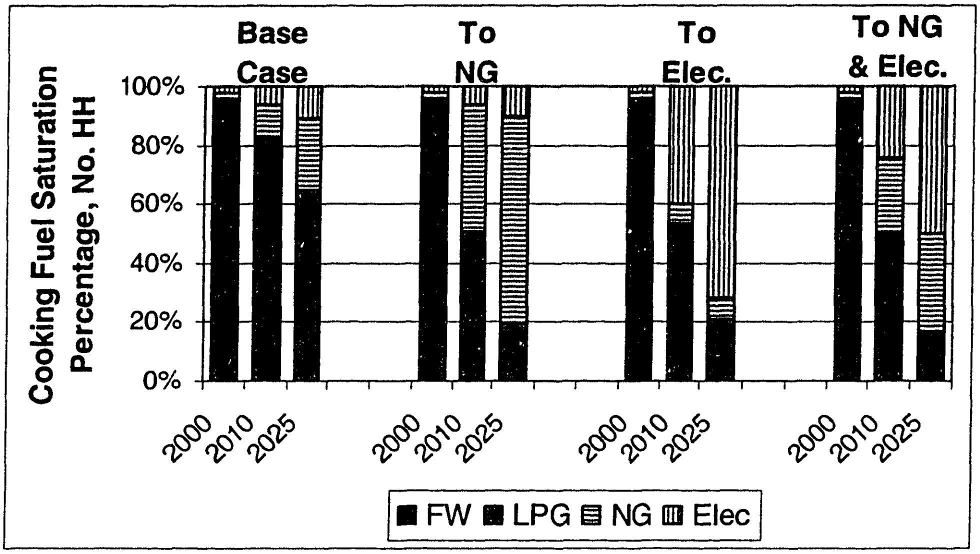

Figure 25. MCMA Residential Cooking Fuel Saturation under Fuel-switch Option Set, As Modeled 2000 & 2025, Changing Climate

The Base Case was modeled to include some switching from LPG to NG and a smaller degree of switching to electricity, as expected by MCMA energy planners. The option that encouraged a switch to natural gas, as modeled, is represented by 75 percent of homes (over five million) using natural gas for cooking by 2025. This large degree of switching requires very large infrastructure changes. The electricity switch is modeled as the same amount of switch, requires less infrastructure changes, but more household appliance purchases. The third option modeled was one in which households switch to both NG and electricity.

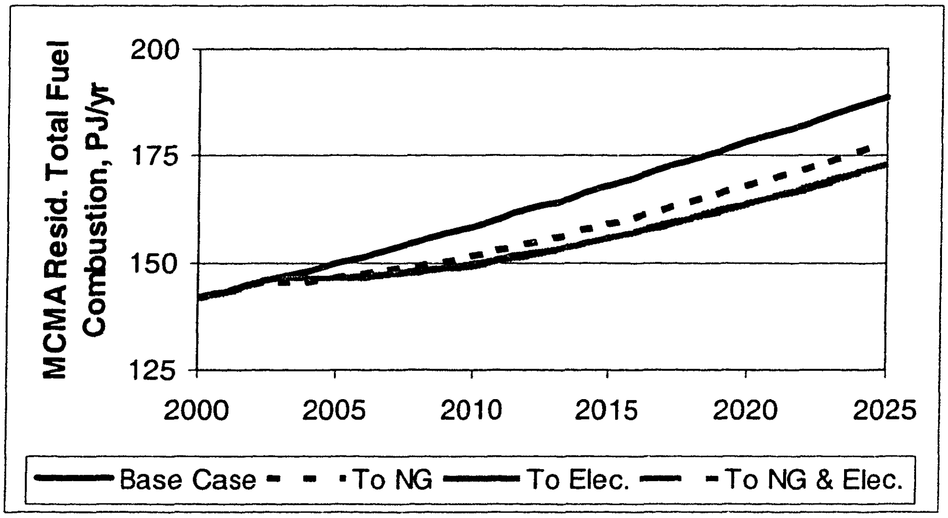

Figure 26. MCMA Residential Fuel Consumption under Fuel-switch Option Set, As Modeled 2000-2025, Changing Climate

As shown, a switch from LPG to natural gas and electricity for cooking saves residential fuel consumption (about eight percent in 2025), because these fuels have a higher energy content and the appliances that use them are more energy efficient. What is not represented in this graph, however, is the increase in fuel used for electricity generation (about 11 MJ for every 4 MJ consumed by households).

Switching to NG from LPG decreases emissions of PM10 and NOx but slightly increases emissions of other pollutants. Switching to electricity from LPG does not result in overall emissions benefits, but does move these emissions outside of the Mexico City Valley, thereby contributing to local air quality improvement. Because switching to NG is more likely, it is the focus of the following emissions comparison. Figures 27 and 28 below translate some of the fuel consumption values above in to emissions for the fuel switching to NG for cooking and water heating options are shown. The options that have been shown so far represented a switch of up to eight percent of household using LPG per year. However, this degree of switching, the amount considered possible according to existing Energy Ministry plans and natural gas distribution contracts, was found to only slow the rate emissions increase so an aggressive scenario was also modeled. Therefore, the emissions from a more aggressive option, in which up to 30 percent of homes using LPG switch to NG per year[20], are also included here.

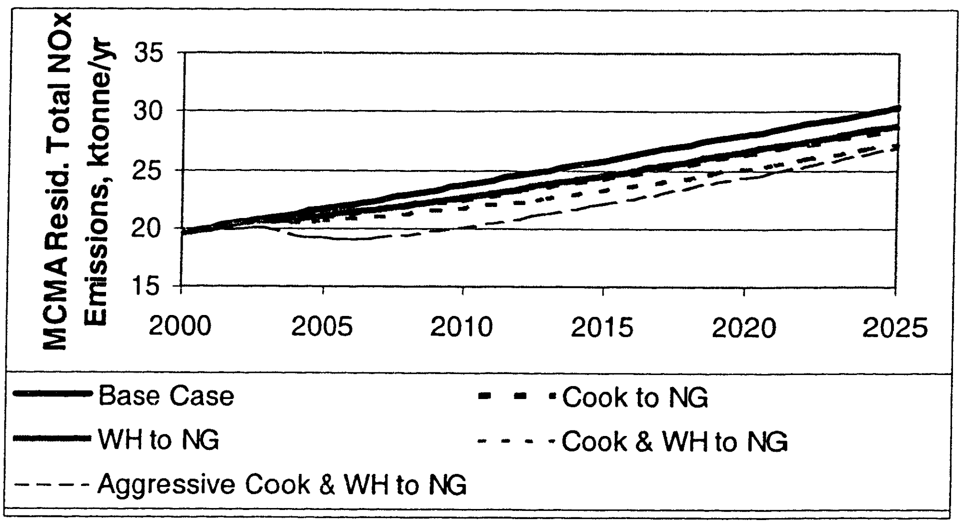

Figure 27. MCMA Residential NOx Emissions for Fuel Switch to NG, As Modeled, 2000-2025, Changing Climate
Note: WH = Water Heating

In 2025, even the aggressive scenario could not even stabilize of NOx emissions; emissions were only 11 percent less than the Base Case. The aggressive option results in a large immediate drop as almost all of the homes switch to NG in the first few years, but then the population growth overwhelms this improvement. This speed of switching is unlikely, however, because this would require almost every home in the MCMA to switch to NG well before 2025, requiring very large infrastructure investments and an elimination of the LPG market. So, to reduce residential NOx emissions, something in addition to switching from LPG to NG must be considered.

[20] As the number of homes using LPG decreases, this 30 percent represents a smaller and smaller number.

Note that emissions shown include electricity generation for residential consumption. Figure 28 shows what happens to residential NOx emissions when households switch to electricity for cooking and water heating.

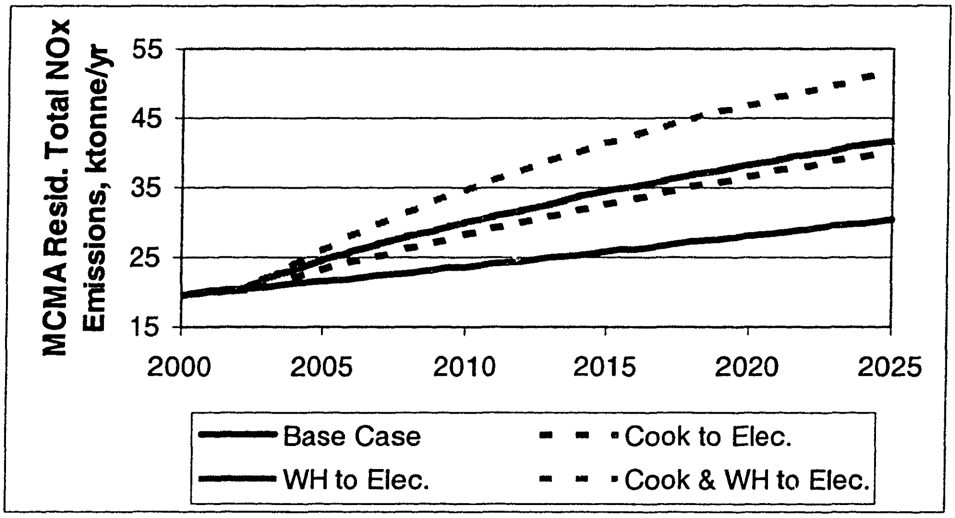

Figure 28. MCMA Residential NOx Emissions for Fuel Switch to Electricity, As Modeled, 2000-2025, Changing Climate

As explained earlier, switching to electricity increases NOx emissions but moves them outside of the valley, a tradeoff decision makers must make. A large number of households switch to electricity (modeled as shown above in Figure 25), residential NOx emissions could increase up to 70 percent, as shown here.

Table 18 below summarizes residential emissions for several fuel switching options, in comparison to base case emissions, for each of the three future stories. The options shown include switching for both cooking and water heating end-uses, at "non-aggressive" levels.

Table 18. Residential Fuel Switching Option Performance (Total NOx Emissions) Under 3 Future Stories, As Modeled

	Base Case	To NG	To Elec	To NG & Elec.
FS: Divided City				
2000-2025 NOx Emissions (ktonne)	637.6	591.9	915.2	811.7
2025 NOx Emissions (ktonne)	29.9	26.9	49.6	42.0
% Change (2000 to 2025)	52%	37%	152%	114%
FS: Changing Climate				
2000-2025 Emissions	645.6	593.7	959.2	857.5
2025 Emissions	30.4	27.2	52.0	46.5
% Change	55%	38%	165%	137%
FS: Growth Unbound				
2000-2025 Emissions	642.7	596.7	921.8	811.7
2025 Emissions	29.2	26.2	48.3	42.0
% Change	48%	33%	146%	114%

The figure shows the change from 2000 to 2025 in each of the scenarios – emissions increase in the Base Case as well as after implementation of the fuel switching options. The effect of the options can be estimated by subtracting the percent change (2000 to 2025) of the option from the base case. Switching to NG slows the emissions increase but switching to electricity has the opposite effect.

The model results have shown that switching from LPG to NG for household end uses decreases emissions of NOx and PM10. Showing results under each of the future stories allows a sensitivity analysis to be performed; it shows which future story characteristics play a role by effecting fuel consumption and emissions reduction potential. The fuel switching to NG option is most effective under the Changing Climate future story, in which household income equalization, environmental awareness and governmental influence is strongest.

The tradeoffs, shown later in this chapter, also demonstrate that this same switch to NG will reduce residential sector costs, even with assumptions of infrastructure and equipment costs associated with increased natural gas usage.

Lighting Efficiency Option Set

Electricity consumption under the lighting efficiency option set is shown below in Figure 29. Electricity consumption can be directly correlated to emissions using the emission factors in Table 10 above. Because the same trend applies to both, only electricity consumption is shown here. As with fuel switching, an aggressive option was necessary to result in significant gains. This option requires that, by 2025, 80 percent of households switch from incandescent bulbs to CFLs.

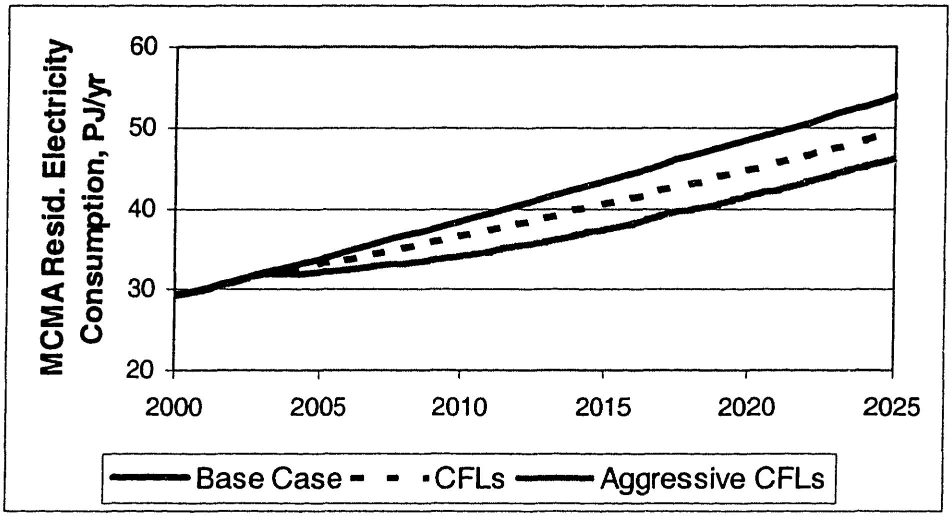

Figure 29. MCMA Residential Total Electricity Consumption under Lighting Efficiency Option Set, As Modeled, 2000-2025, Changing Climate

The Base Case shows an 80 percent increase in residential electricity consumption during the 26-year period, primarily due to the increase in population. The lighting efficiency options reduce this rate of increase; in the year 2025 the CFL option shows a six percent decrease in total electricity consumption and the aggressive CFL option shows a 12 percent decrease in total electricity consumption. The reduction is more dramatic when evaluating the change in lighting electricity consumption, which represented about one-fourth of residential electricity demand in 2000. These options correspond to a 38 percent and 64 percent reduction in total residential lighting electricity consumption, as shown in Figure 30. Key costs associated with these options include purchase costs of new bulbs and labor to perform energy audits. Households can also expect electricity savings that outweigh higher purchase costs for new bulbs.

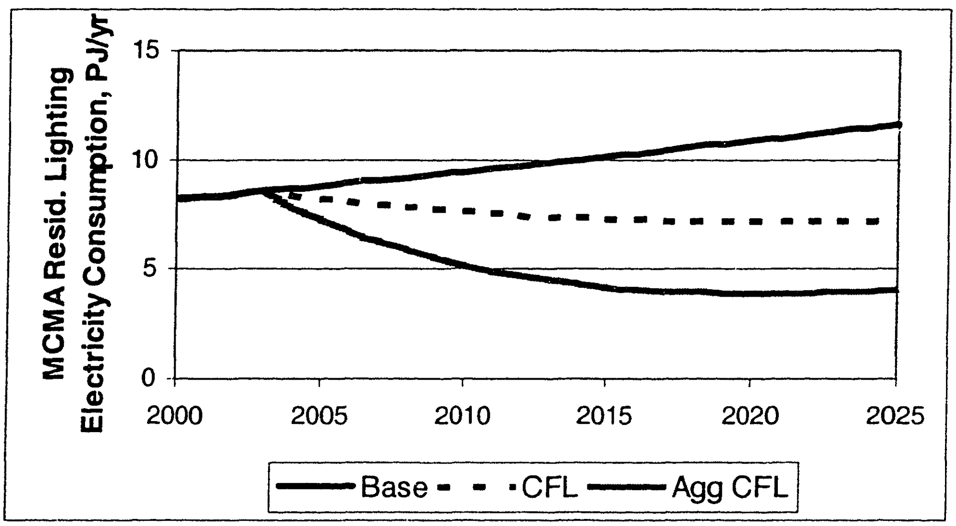

Figure 30. MCMA Residential Total Lighting Electricity Consumption under Lighting Efficiency Option Set, As Modeled, 2000-2025, Changing Climate

Appliance Efficiency Option Set

The second set of efficiency options modeled is electric efficiency of major household appliances. The electricity consumption of household appliances, as mentioned above, constituted about one-fifth of household energy consumption and one-half of household electricity consumption in 2000. Figure 31 below represents the electricity consumption expected if the new standards described earlier are put in place in 2005. Electricity consumption can be directly correlated to emissions using the emission factors in Table 10 above. Because the same trend applies to both, only electricity consumption is shown here.

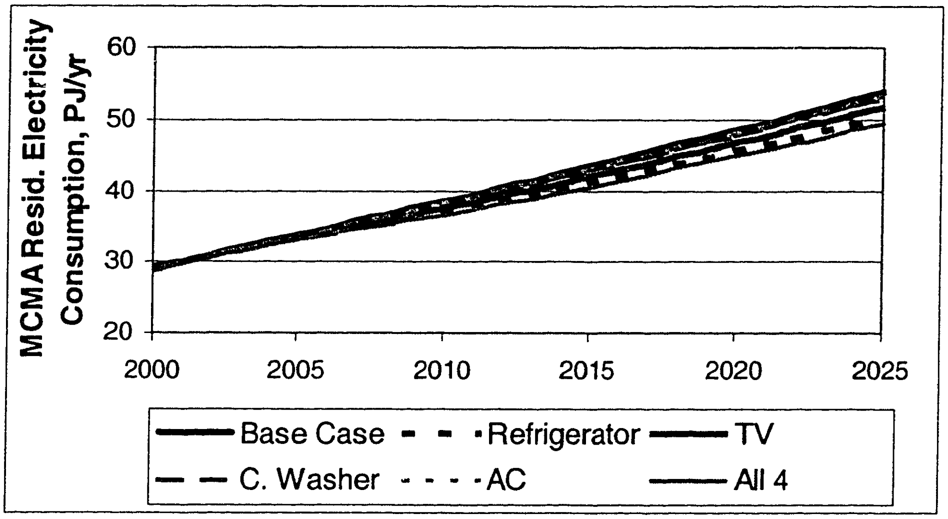

Figure 31. MCMA Residential Total Electricity Consumption under Appliance Efficiency Option Set, As Modeled, 2000-2025, Changing Climate

The Base Case shows an 80 percent increase in residential electricity consumption during the 26-year period. Implementation of new standards in 2005 for all four appliances results in only a nine percent reduction from the Base Case in 2025. This shows that household growth will overwhelm the effect of new and replacement purchases of more efficient appliances. Although the consumption reduction due to these standards is not significant when evaluated at the residential level (as above with the lighting options), significant reductions can be expected when looking at only appliance electricity consumption, as shown in Figure 32.

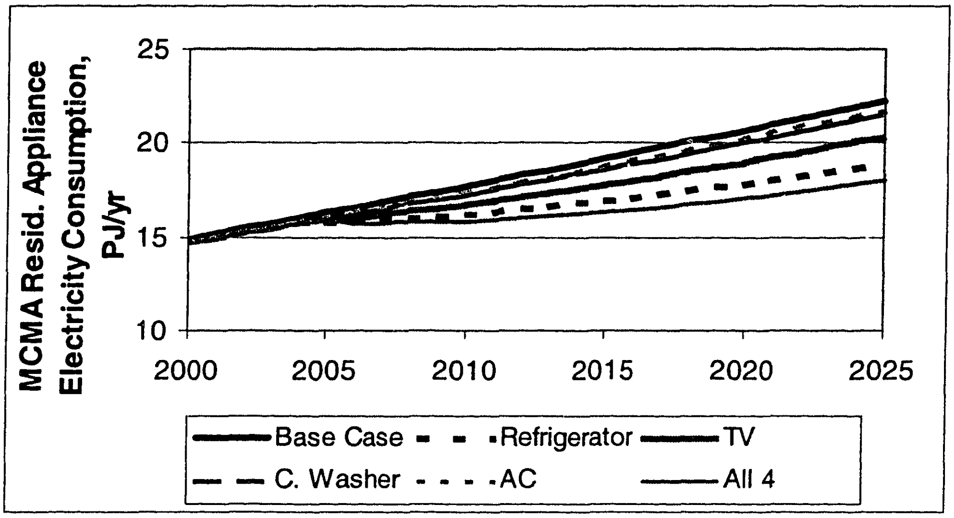

Figure 32. MCMA Residential Appliance Electricity Consumption under Appliance Efficiency Option Set, As Modeled, 2000-2025, Changing Climate

The option modeled as increased efficiency of all four appliances decreases residential appliance electricity consumption by 24 percent in 2025. Improved standards for refrigerators and TVs were the next most success, at 19 percent and 11 percent respectively, primarily due to their higher energy intensities and household saturation values. There are no costs associated with the appliance efficiency options because they were modeled by assuming that all new purchases occurred through natural turnover and not forced by a new program.

Table 19 below provides an electricity consumption summary for the lighting and appliance efficiency options, in comparison to base case consumption, for each of the three future stories. The lighting efficiency option shown is the non-aggressive switch to CFLs. The appliance efficiency option shown assumes Energy Star level standards in force in 2005 for all four appliances modeled.

Table 19. Residential Efficiency Option Performance (Total Electricity Consumption) Under 3 Future Stories, As Modeled

	Base Case	Lighting	Appliances (All 4)	Lighting + Appliances
FS: Divided City				
2000-2025 Elec. Con. (PJ)	1,049.4	991.5	994.4	936.5
2025 Elec. Con. (PJ)	52.4	47.8	48.2	43.7
% Change (2000 to 2025)	79%	63%	66%	50%
FS: Changing Climate				
2000-2025 Elec. Con.	1,068.9	1,012.4	1,011.4	954.8
2025 Elec. Con.	53.8	49.4	49.5	45.1
% Change	84%	69%	70%	55%
FS: Growth Unbound				
2000-2025 Elec. Con.	1,063.8	1,007.4	1009.3	952.8
2025 Elec. Con.	51.7	47.4	47.6	43.3
% Change	77%	62%	64%	49%

Within the range of modeling uncertainties, the lighting and appliance option appears to reduce approximately the same amount of electricity consumption. If only one option can be chosen for implementation, decision makers should evaluate the costs of each program – as modeled, the cost of more stringent appliance standards is less costly to the residential sector than a program that promotes the modeled degree of CFL use. The costs are an important factor for these options; more information should be collected and costs to other sectors evaluated before policies are designed.

In this case, the Changing Climate future story is not the most effective. This is a product of the way the options were modeled – fuel switching was assumed to be a percentage of households and a function of future story characteristics; lighting options were assumed to be part of a program in which the number of participant households was predetermined and not a function of future story.

Fugitive Emissions Option Set

The final set of options that will be described here is that relating to LPG leakage reduction. Two of the options evaluated are included in the reference cases – Ideal PROAIRE and MIT PROAIRE. Because only minor NMHC reductions resulted from these – the Ideal PROAIRE results in a nine percent reduction in 2025 NMHC emissions from the Base Case and a nine percent reduction in cumulative 2000-2025 NMHC emissions from the Base Case (under the Changing Climate future story); the MIT PROAIRE results in a three percent reduction in 2025 NMHC emissions from the Base Case and a two percent reduction in cumulative 2000-2025 NMHC emissions from the Base Case – an additional option was modeled that was more aggressive. This aggressive option involves a program that reaches 180,000 homes annually from 2003-2025. This amounts to over 4 million homes. In each of these homes, LPG leakage is reduced by 40 percent (the same reduction planned in the Ideal PROAIRE). The residential NMHC emissions reductions from these options are shown in Figure 33. The emissions shown include those from fuel combustion (seven percent of 2000 NMHC emissions) and solvent usage (17 percent of 2000 NMHC emissions, in addition to LPG leakage related emissions.

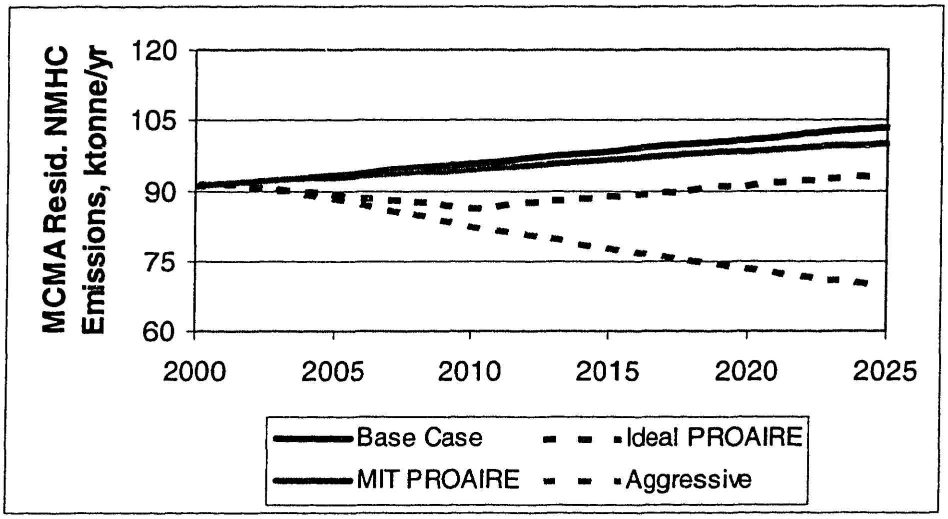

Figure 33. MCMA Residential NMHC Emissions under Fugitive Emissions Option Set, As Modeled, 2000-2025, Changing Climate

As shown, the Base Case shows an increase in residential NMHC emissions of about 15 percent during the 26-year period. The aggressive option modeled results in a 30 percent reduction in 2025 NMHC emissions from the base case and a 20 percent reduction in cumulative 2000-2025 NMHC emissions from the base case. This level of significant emissions, however, increases the option cost significantly. Costs include labor and equipment for repair of appliances. Fugitive emission options are also important because they allow for some fuel expenditure savings for the consumer along with reduced emissions and exposure.

Table 20 provides a summary of some of these key options and their NMHC emissions reductions under each of the three future stories. As shown above and in this table, the rate of emission increase is slowed by the PROAIRE options, but only the aggressive (and perhaps infeasible) option causes a decrease in NMHC emissions.

Table 20. Residential LPG Reduction Option Performance (Total NMHC Emissions) Under 3 Future Stories, As Modeled

	Base Case	Ideal PROAIRE	MIT Realistic PROAIRE	Aggressive
FS: Divided City				
2000-2025 NMHC Emissions (Mtonne)	2.51	2.32	2.47	2.09
2025 NMHC Emissions (ktonne)	102.4	92.7	99.1	69.0
% Change (2000 to 2025)	12%	1%	8%	-24%
FS: Changing Climate				
2000-2025 Emissions	2.53	2.34	2.49	2.10
2025 Emissions	103.4	93.5	100.1	69.7
% Change	13%	2%	10%	-24%
FS: Growth Unbound				
2000-2025 Emissions	2.53	2.34	2.49	2.10
2025 Emissions	100.1	90.3	96.8	66.4
% Change	9%	-1%	6%	-27%

As shown, the Ideal PROAIRE Reference Case is able to reduce residential NMHC emissions from 2000 levels in the Growth Unbound future story but not the other two. This should caution decision makers from designing a policy without evaluating future uncertainties. The aggressive option is the most effective, and reduced NMHC emissions by about one-fourth in each future story, but may be infeasible because of the scope and cost of this option, the way it was modeled. Another important factor is that the necessity of this option will decrease if more consumers switch away from LPG to alternative fuels.

Like the efficiency options, these fugitive emission options were modeled as program that reached a predetermined number of households per year of the program. Therefore, the future story characteristics affect the results through the relative (percentage), not absolute (mass), amount of emission reductions within each future story. In other words, the aggressive strategy reduced the same quantity of emissions in each future story (0.42 Mtonne during the 26 years), within rounding errors.

Leakage from distribution and storage of LPG is another important category of emissions; these emissions are included in the residential sector but emission reduction options have not yet been modeled.

Reference Case and Option Tradeoffs

The emissions from each of these individual options and combinations of several options were modeled and the attributes recorded under each scenario. This section will describe the results of some of the best options, in terms of emissions reduction and costs. It will also provide information on tradeoffs, option timing, and combinatorial effects.

Before moving to the tradeoff analysis, Table 21 provides a summary of the costs associated with some of the options described above; options that reduce residential costs are highlighted.

Table 21. NPV Residential Costs for Reference and 4 Additional Options

Strategy (FS: Changing Climate)	**Present Value Costs, Billion US$ (NPV 2000 – 2025, r=5%)**			
	Total	**Fuel**	**Equipment**	**Option**
Base Case	160.4	149.4	11	0.013
Ideal PROAIRE	160.4	149.3	11	0.094
MIT PROAIRE	160.4	149.4	11	0.0333
Cook & WH to NG	154.4	143.2	11.2	0.022
Cook & WH to Elec.	185.5	173.7	11.9	0.022
CFLs	156.8	145.7	11	0.016
4 Appl. Stnds.	156.7	145.7	11	0.013
Strategy	**Cost Percent Change (from Base Case)**			
Ideal PROAIRE	0%	0%	0%	623%
MIT PROAIRE	0%	0%	0%	156%
Cook & WH to NG	**-4%**	**-4%**	2%	69%
Cook & WH to Elec	16%	16%	8%	69%
CFLs	**-2%**	**-2%**	0%	23%
4 Appl. Stnds.	**-2%**	**-2%**	0%	0%

Fuel is shown to be the primary expense for the residential sector, representing over 90 percent in the Base Case. As shown, many of the options have costs changes because of fuel switches and efficiency improvements. Cost decreases are due to fuel savings from more efficient fuels and appliances. Costs increases are incurred due to program and other option costs such as labor, infrastructure construction, as well as fuel prices increases and appliance retrofits. Switching to natural gas from LPG is shown to save the residential sector four percent in fuel costs during the 26-year period. As mentioned earlier, this option saves costs even if the consumer price of natural gas increases to above LPG prices on an energy basis.

Remember that this does not yet include all of the costs associated with options – infrastructure and some program costs have not yet been estimated. As shown, these costs will be very important to include because, without them, the fuel savings associated with these residential options actually *saves* money. Another consideration, beyond total sector costs, is costs per household. Costs per household follow the same trends as above-switching to natural gas saves annual fuel expenditures for each household and purchases of new appliances or lighting costs households more initially but is usually compensated by improved efficiency and related fuel savings within a few years.

Most of the options target specific pollutants, so their combinatorial effects on emissions can be summed. However, option costs are not strictly additive, if a program or policy is designed to conduct more than one option using shared resources. The figures below will show some of these tradeoffs.

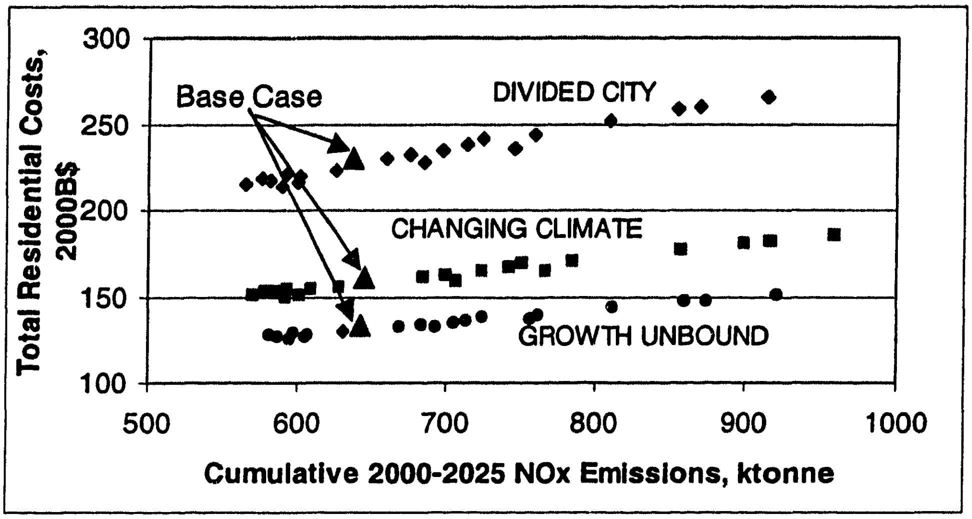

Figure 34. Cumulative Residential NOx Emissions and Total NPV Residential Sector Costs for Fuel Switching Options, As Modeled

For simplification, Figure 34 highlights the effects of the future stories on the fuel switching option. The Base Case, under each future story, is indicated by a triangle symbol. Options with less NOx emissions than the Base Case include fuel switches to natural gas or solar. Options with NOx more emissions than the Base Case include fuel switches to electricity. In each future story, switching to NG for cooking and switching to NG or solar energy for water heating is preferable based on NOx and PM10 emissions as well as costs, contingent upon the assumption that NG will continue to be less expensive. However, a sensitivity analysis has shown that NG will still be financial preferable even if the retail cost is increased by one-half (based on currently estimate future fuel prices), which is slightly less than the cost of LPG on an energy basis. Figure 34 also shows that switching to electricity increases NOx emissions but moves them out of the valley.

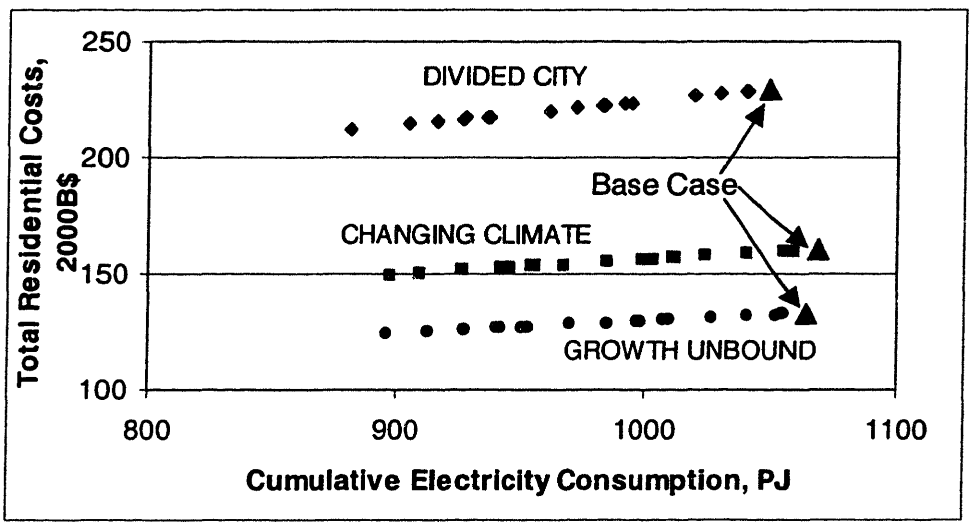

Figure 35. Cumulative Residential Electricity Consumption and Total NPV Residential Sector Costs for Efficiency Options, As Modeled

Figure 35 shows the cost and emissions tradeoffs for the residential electricity efficiency option sets. As discussed above, increasing lighting and appliance efficiency decreases residential electricity consumption and household energy expenditures. The Base Case is indicated by a triangle signal – electricity consumption decreases with the addition of each appliance standard and CLF program. The most reduction is through an aggressive CFL program and new standards for all four appliances. This tradeoff graph shows a decrease in cost with these options, indicating that the electricity expenditure savings are greater than the cost of new equipment.

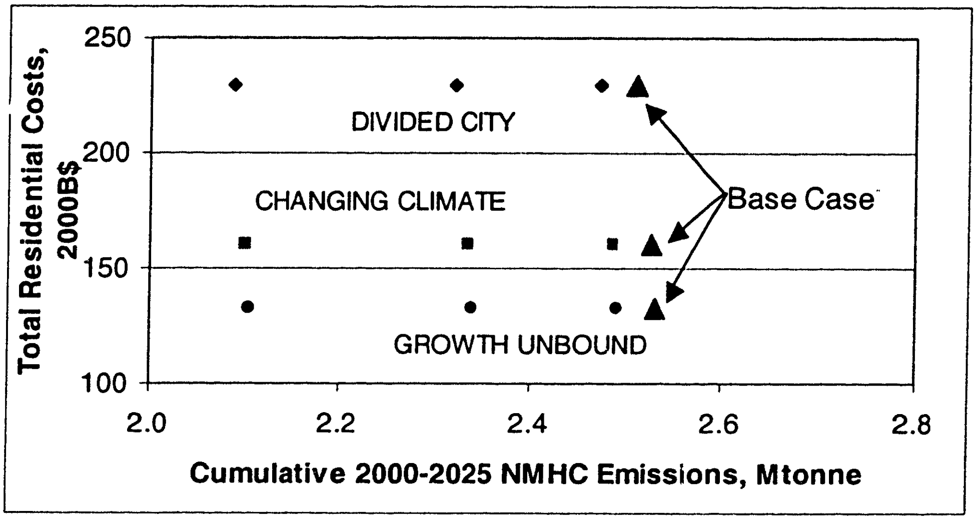

Figure 36. Cumulative Residential NMHC Emissions and Total NPV Residential Sector Costs for LPG Leakage Reduction Options, As Modeled

Figure 36 shows the cost and emission tradeoffs for the LPG leakage reduction options sets. The Base Case is indicated by a triangle symbol. All LPG leakage reduction options modeled reduce NMHC emissions and slightly reduce costs through fuel savings. In order of increasing reduction of NMHC emissions, the dots represent MIT PROAIRE, Ideal PROAIRE and Aggressive. As shown earlier, the performance is also slightly affected by future story characteristics.

The LPG reduction option becomes less effective as more homes switch from LPG to alternative fuels. The NMHC emissions benefit of the aggressive LPG option is reduced as more households switch away from LPG to NG. A comprehensive strategy, to target more than one pollutant, would be to encourage households to switch to NG and solar to reduce NOx and PM10 emissions and to focus leakage reduction measures on those households that do not switch.

Tradeoffs could also be shown for combinations of these option sets. However, each set targets different pollutants, so results for combinations are simply found by summing the individual options, except for the fuel switch – LPG leakage reduction dynamics mentioned above.

CHAPTER 9. RECOMMENDATIONS AND CONCLUSIONS

The General Law of Ecological Balance and Environmental Protection of 1988, its amendment of 1996 and the development of PICCA and two PROAIREs were monumental steps in environmental legislation and regulation in Mexico. However, residential sources and those in which direct exposure is the greatest are often overlooked because of their lesser overall contribution to regional emissions.

Policy Recommendations

The residential sector has seldom been a focus of pollution abatement activities in the MCMA. This is understandable because of the small role this sector plays regarding regional air pollution, but exposure and the impact of continued growth should increase the attention it receives. Because there is little experience with programs devoted to residential air pollution, decision makers will be charting new territory. Whatever the program or policy design, decision makers should first try to work with existing organizations, such as FIDE, that have historically been working at the household level to coordinate efforts and resources and/or learn from their experience. Other countries, such as the US, that have developed residential energy efficiency and air pollution initiatives should also be used as role models. Decision makers should also consider the cost allocation of the options and the ability to pay by different entities. Robustness of option success across future uncertainties is another important factor and is related with the cost of implementation and other feasibility issues.

The modeling efforts show that several options are feasible for the residential sector and are able to reduce emissions at low costs, including fuel switching and efficiency improvements. The options modeled were bottom up changes in the residential sector structure. They represent a non-exhaustive set of potential measures to reduce household generated emissions. However, emissions reductions must be considered in conjunction with exposure. Based on the option modeled, decision makers must now design policies that would lead to these types of changes.

Fuel switching could be promoted through new energy pricing practices, such as electricity tariffs and billing strategies. Energy pricing strategies that increase the price of fuel can encourage energy conservation and fuel switching as well. To promote energy efficiency with social equity, energy pricing should provide a minimum level of services to all income levels, maintain energy prices in relation to DSM programs to allow access to efficient technology, reduce subsidies to large consumers, and simplify billing structure for all users. At high-income levels, conservation is not a priority because energy expenditures are a small share of total expenses. At low-income levels, absence of financial resources limits the purchase of efficient appliances and substitution of fuels.

Lighting and major appliances are highly visible to the public and, therefore, provide a way to publicize local, regional and global environmental issues related to energy consumption. FIDE's ILLUMEX program could be used as a model for the lighting efficiency option, which allows households to switch to CFLs in way that is not cost-prohibitive. Because the cost of CFLs have decreased since the program was initiated, fewer costs subsidizes are likely to be required, increasing the ability for more home participation.

Improved appliance efficiencies would have straightforward implementation though changing existing standards for electric and non-electric appliances, but this would probably require federal action. Standard harmonization between the US and Mexico would also encourage trade between them, by reducing conformity assessment costs, decreasing regulatory burden, reducing manufacturing and distribution costs and getting innovations to the market faster (Wethje, 2002). Turnover of the existing stock of appliances could be encouraged through subsidization at any step of the purchase – connection fees if a fuel switch is related to the new appliance, or purchase of the appliance itself. In the same way government loans would encourage purchase of new appliances by low-income households. Studies of U.S. appliance efficiency standards have shown a benefit/cost ratio greater than two; a negative net cost is possible for Mexico as well (Koomey, 1998). A voluntary program, similar to the U.S. EPA Energy Star program, could also be considered if the survey reveals a Mexican market for "green" products.

Government restrictions to reduce leakage could include anti-leakage regulations. This could include maintenance and repair of household appliances, connection lines, distribution lines and storage tanks and facilities. There is already government and academic work being done to understand the impact of LPG leakage; gaining support to reduce this leakage is probably the most feasible of the options considered.

Other options, that could not be modeled because their emissions impact in the MCMA were uncertain, include use of less volatile solvents and education programs as part of demand side management (DSM) programs. Less polluting and hazardous solvents currently available in the US could be promoted in Mexico and the MCMA, perhaps through an education campaign on homemade alternatives or commercial substitutes. Increased awareness of the environmental and health impact of household activities and consumption will enhance the effectiveness of any emissions reduction strategy. Educated consumers can make better informed fuel choice and consumption decisions, can better maintain appliances to increase energy efficiency and prevent leakage, and can select household appliances and products that benefit them in the long-run in terms of emissions, health, and monetary savings. A survey of the results of FIDE energy audits shows that suggested measures resulted in savings of about 15 percent per household.

Barriers/Issues to Action

Although the model and tradeoff analysis provides us with valuable insight into the residential sector and possible actions to mitigate air emissions, several feasibility factors must be considered before action is taken.

Currently, political forces are dealing with social problems such as unemployment, healthcare and social security. As shown in the survey, the environment, although generally recognized to be important, is not a priority of many residents in Mexico City. Residents and governments alike will experience tensions between the benefits and environmental and health costs associated with increased economic development and prosperity.

Energy prices should be adjusted so that they reflect the true cost of service, requiring cooperation between Hacienda and Pemex to determine a new structure. Residential bill formats should be simple to comprehend so that consumption is more visible. The same is true for appliance efficiency–efforts should be made to make the consumer aware of the impact of their consumption. Energy audits and education programs could serve this goal.

Although lower income classes are those who are the most exposed to the adverse effects of air pollution in the MCMA, they are the ones who will suffer most in mitigation efforts. Since the current government is abolishing several subsidies, there is no economic compensation for people who do not have the ability to change their behavior, through switching to less expensive fuels or purchasing more efficient appliances, when confronted with changing costs. These issues must be considered.

Coordination will be a key factor in the success of any options. Enforcement and mistrust between the government and private entities has led to the insufficient results of existing appliance efficiency standards (Friedmann and Sheinbaum, 1998). Numerous agencies and programs created to solve similar problems should work together to find feasible and cost-effective solutions.

As mentioned, financing of the options considered will affect their success. An amendment to the LGEEPA could place the jurisdiction of the MCMA in the hands of SEMARNAT directly. This would allow federal financing of environmental projects, with state and local governments contributing with human resources for enforcement purposes.

The current Mexican government has announced that Mexico is on an "environmental crusade" and has pushed heavily for decentralization of environmental enforcement (EIA, 2001). Although the goal of these programs is to minimize conflicts between different regulating agencies, it will also result in a decreased authority for the SEMARNAT and its subdivisions. Efforts to reduce pollutant exposure and emissions from the residential sector should be harmonized across the DF and EM, to provide the same level of services and programs regardless of political boundaries and other socioeconomic conditions. Harmonization would also allow for expanded appliance markets across North America.

Limitations to Research Findings

Almost all surveys and analyses performed related to residential energy consumption and behavior stress the importance of continued collection of information. This information must be collected to determine the potential for energy savings and direct the formulation of residential energy policy. Information on fuel and end-uses for different regions, income groups and clusters must be determined.

The survey, while representative of the entire MCMA, was performed at a relatively small scale. It was essentially a test of the instrument and the methodology, and an indicator that such information useful for characterizing the residential sector. If continued, it would be useful to expand this survey to gather information on other areas that are currently under researched and uncertain. This includes:

- Waste disposal practices – Are there trash fires? Is anyone recycling and do they want to?
- Informal commercial activities – Which homes have commercial activities in their home? By location? What are the characteristics that correlate to this occurrence?
- Vehicle ownership and use – What types of homes own and use cars?
- Outdoor activities – Is outdoor fertilizer/pesticide use a concern?
- Solvent use and exposure – What solvents are being used and how?

Finally, continued and consistent data collection is essential (Friedmann and Sheinbaum, 1998).

Future modeling efforts should disaggregate the MCMA into clusters/groups that behave similarly, in terms of energy consumption and pollutant emissions. This could be by location, income or other variables, which have initially been determined by the survey.

Improvements to the model include:
- Modeling by economic class and inclusion of informal settlements
- Analysis by delegation/municipality and eventually neighborhood (allows for more specific education and feedback)
- Inclusion of additional missing residential Emissions Inventory sources – household trash disposal and burning, household yard chemicals
- Exposure ranking/weighting (Kandlikar, 2000) added to the tradeoff and linked to health effects modeling

Final Thoughts

The government has begun to address air pollution problems in the MCMA, but its focus so far has been on the larger polluters: transportation and industry. As household pollutants are associated with serious health problems, this focus should shift. The residential survey and model has shown that there are still many ways to reduce emissions from the residential sector and, thus, local, regional and global air pollution, and that many of these reductions are cost-effective and can reduce direct exposure to harmful compounds.

There should be continued work to analyze policy success and failure and proposed regulatory improvements, as well as continued monitoring of the residential sector's activities, attitudes and health. The residential options modeled are not exhaustive but provide a strong sampling of the potential for future environmental improvements in the residential sector and those influenced by household activities. There is a great need for coordination and policy integration within air pollution abatement strategies and governing bodies.

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APPENDIX

Household Survey

Técnica

Investigación Interdisciplinaria S.C.

NO. CUESTIONARIO [ ][ ][ ][ ][ ] 1 2 3 4 5

NO. PROYECTO [ ][ ][ ][ ] 8 9 10 11 — 12 — 13 14

NOMBRE DEL ENTREVISTADO ____________________

DIRECCIÓN: ____________________

TELÉFONO: ____________________

LUGAR DE LA ENTREVISTA: ____________________

FECHA DE APLICACIÓN

DIA [ ][ ] 28 29 **MES** [ ][ ] 30 31 **AÑO** [ ][ ] 32 33 **HORA INICIO** [ ][ ] 34 35 : [ ][ ] 36 37 **HORA FINAL** [ ][ ] 38 39 : [ ][ ] 40 41 **DURACION MINUTOS** [ ][ ][ ] 42 43 44

NO. ENCUEST [ ][ ][ ][ ] 49 50 51 52

NIVEL SOCIOECONÓMICO	ALTO			MEDIO			BAJO			
AMAI	9	8	7	6	5	4	3	2	1	68

ESTOS DATOS SE TOMARAN DE LA SECCIÓN CORRESPONDIENTE

¿CUAL ES LA ESCOLARIDAD DEL JEFE DE FAMILIA, ES DECIR, CUAL ES EL ULTIMO GRADO ESCOLAR QUE CURSO?

	JF	ENT.
NO ESTUDIO NADA	1	1
PRIMARIA INCOMPLETA	2	2
PRIMARIA COMPLETA	3	3
SECUNDARIA INCOMPLETA	4	4
SECUNDARIA COMPLETA	5	5
CARRERA COMERCIAL	6	6
CARRERA TÉCNICA	7	7
PREPARATORIA INCOMPLETA	8	8
PREPARATORIA COMPLETA	9	9
LICENCIATURA INCOMPLETA	10	10
LICENCIATURA COMPLETA	11	11
DIPLOMADO	12	12
MAESTRÍA	13	13
DOCTORADO	14	14

Y ¿CON CUANTOS(AS)... CUENTAN EN SU HOGAR?

	0 1 2 3 4 5 6	76
APARTE DE LOS BAÑOS, ¿CON CUANTAS HABITACIONES CUENTA LA VIVIENDA?	______	77 78
CONTANDO TODOS LOS FOCOS DE LAS LÁMPARAS DEL TECHO Y DE TODO EL HOGAR,		79 80
DÍGAME CUANTOS FOCOS TIENE USTED EN SU	______	81
CASA?(CONTAR TAMBIÉN LAS BOMBILLAS DE NEON)		82

INDICE AMAI

Buenos días/tardes, mi nombre es _______________y estamos haciendo un estudio sobre salud en la Ciudad de México para un proyecto del **Instituto Tecnológico de Massachussets**, Estados Unidos. Este estudio evalúa las formas de reducir la contaminación en la Ciudad de México y mejorar la salud pública de los habitantes de la Ciudad.

En este estudio no hay respuestas buenas ni malas, de lo que se trata es que nos dé su punto de vista. En caso de no entender alguna pregunta, por favor solicite que se la explique de otra manera. La información de esta encuesta es confidencial. Gracias por su ayuda.

ENCUESTADOR SOLICITAR ENTREVISTAR AL JEFE DE FAMILIA

SECCIÓN I PERFIL DEL HOGAR

1.- ¿Es usted el responsable de tomar las decisiones relacionadas con el funcionamiento de este hogar y las compras y adquisiciones que se hacen?

SI...........**1 (CONTINUAR)**
NO.........**2 (TERMINAR)**

Vamos a hablar sobre las personas con las que vive y su hogar.

1.A HABITANTES DEL HOGAR

1. Incluyéndose a usted, cuantas personas viven en su casa?

____

2. ¿Cuál de las siguientes opciones describe mejor su casa (no su edificio, solo su casa)?

Casa unifamiliar.................. **1**
Casa donde viven varias familias...............**2**

4.¿Su casa es ?

Propia.. 1
Rentada a un casero....................... 2
Rentada directamente al dueño...... 3
No sabe. 4
Otro ....5 (Especifique) ____________________

5. ¿Cuánto tiempo lleva viviendo en este domicilio ?

_______________ años
_______________ meses

SECCION 1: PERFIL DEL HOGAR

Las siguientes preguntas se refieren a las cuatro personas de mayor edad en esta casa, incluyéndose a usted mismo

	ENTREVISTADO	**FAMILIAR 1**	**FAMILIAR 2**	**FAMILIAR 3**
6. ¿Dígame las edades de las cuatro personas de mayor edad que habitan este hogar, comencemos por la de más edad. ¿y luego quien sigue?, ¿y luego?, ¿y luego?...				
7. Sexo	Masc....1 Fem.....2	Masc....1 Fem.....2	Masc....1 Fem.....2	Masc....1 Fem.....2
8. Vive permanente en esta casa ?	Si........1 No......2	Si........1 No......2	Si........1 No......2	Si........1 No......2
9. Vive temporal u ocasionalmente en algún otro lugar durante el año?	*Donde?* ________ Cuánto tiempo?____ Mes(es)	Donde? ________ Cuánto tiempo?____ Mes(es)	Donde?________ Cuánto tiempo?____ Mes(es)	Donde?________ Cuánto tiempo?____ Mes(es)
10. Hasta que grado escolar cursó? MOSTRAR TARJETA 10	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
10a Recibe usted un ingreso?	Si........ 1 No...... 2	Si........ 1 No...... 2	Si........ 1 No...... 2	Si........ 1 No.......2
11. ¿Cuál es su principal fuente de empleo, puesto? MOSTRAR TARJETA 10A	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12
12. ¿Cuántas horas al día trabaja en este trabajo?				
13. ¿Cuántos días a la semana trabaja en este empleo?				
14. ¿Dónde se encuentra su trabajo (Mpio. o Del.)				
15. ¿Cómo se traslada a su trabajo (PREGUNTE CADA UNA Y	1 2 3 4 5 Otro________	1 2 3 4 5 Otro________	1 2 3 4 5 Otro________	1 2 3 4 5 Otro________

	ENTREVISTADO	FAMILIAR 1	FAMILIAR 2	FAMILIAR 3
MOSTRAR TARJETA 15	(especifique)	(especifique)	(especifique)	
16. En promedio, ¿Cuántas veces al día realiza este viaje?				
17. En promedio, ¿Cuánto tiempo le toma llegar al trabajo?				
18. ¿Cuál es su ingreso ? MOSTRAR TARJETA 18	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
19 ¿Tiene una segunda fuente de ingresos?	Sí 1 No 2	Sí		
20 ¿Cuál es su segunda fuente de ingreso?				

21. Además de los residentes descritos anteriormente, cuánta más gente vive en esta casa? ________________

22a Me puede decir también sus edades? ________________

22b. Cuál es el ingreso neto total aproximado del hogar? ________________ pesos (MOSTRAR TARJETA 22B)

1.B ESTRUCTURA DEL HOGAR

Ahora le preguntaré sobre el tipo de edificio en el que vive.

23. De las siguientes opciones ¿Cuál describe mejor el tipo de lugar en el que vive?

Casa Independiente.................................. 1
Departamento (Parte de un edificio de múltiples unidades)............. 2
Condominio horizontal............................... 3
Vecindad.. 4
Otro ....5 (especifique)________________

24. Número de pisos en su casa ______________________________ (no de todo el edificio solo de su unidad)

25. Número de cuartos (incluyendo sala, comedor, etc) **separados en su casa** ______________________________ (no de todo el edificio, sólo su unidad)

26. Número de recamaras separadas en su casa ______________________________ (no de todo el edificio, sólo su unidad)

27. Número de pisos en el lugar ______________________________

28. Número de casas/departamentos en el edificio

____

29. ¿Cuenta con garage en el edificio o casa?
Si 1
No 2

30. ¿Cuál es el tamaño de su casa (superficie) (no de todo el edificio, sólo su departamento) MOSTRAR TARJETA 30

Menos de 100 metros cuadrados.................. 1
Entre 101 y 200 metros cuadrados............... 2
Entre 201y 300 metros cuadrados................ 3
Más de 301 metros cuadrados...................... 4
No sabe... 5

31. ¿En que año se construyó el edificio?
Antes de 1950...................... 1
De 1951 a 1960................... 2
De 1961 a 1970................... 3
De 1971 a 1980................... 4

De 1981 a1990.................... 5
Después de 1991.............. 6
No sabe.............................. 7

32. ¿Cuál(es) de los siguientes servicios tiene? (PREGUNTE CADA UNO)
Agua...................................... 1
Drenaje.................................. 2
Recolección de basura.......... 3
Teléfono................................. 4
TV por cable........................... 5
Internet................................... 6

Ahora pasamos a la seconda sección

SECCIÓN 2: ACTIVIDADES COMERCIALES EN EL HOGAR

Ahora le voy a hacer preguntas relacionadas con negocios desde el hogar.

33. En su casa, se lleva(n) a cabo alguna(s) de las siguientes actividades comerciales? (PREGUNTE POR CADA UNA)

Trabajo de oficina........................1
Venta de comida............................ 2
Reparaciones de casas (como actividad comercial).................. 3
Reparaciones o pintura de automóviles...................... 4
Pintura de casas........................5
Otra ....6 (especifique)____________________
Ninguna............................7

34. Aproximadamente, ¿Cuántas casas en su colonia llevan a cabo alguna de las actividades comerciales mencionadas ?

Menos del 5%.................. 1
Del 6 al 10% 2
Del 11 al 25% 3
Más del 26%.....................4
No sabe.............................5
Ninguna............................ 6

Ahora pasamos a la tercera sección

SECCIÓN 3: APARATOS DEL HOGAR

Esta sección incluye preguntas sobre los aparatos o accesorios que tiene en su casa. Las siguientes preguntas se refieren a la cantidad y antigüedad de los aparatos o accesorios que tiene en su casa.

COCINA / BAÑO	*LUZ*	LIMPIEZA	ENTRETENIMIENTO	

COCINA / BAÑO	LUZ	LIMPIEZA	ENTRETENIMIENTO	CLIMA
35. ¿Tiene estufa? SI.....1 ¿Cuántas?________ NO...2 *¿Qué tiempo tiene su estufa más antigua?*__________ **36. ¿Tiene horno? (No microondas)** *SI.....1 ¿Cuántos?*_____ NO...2 *¿Qué tiempo tiene su horno más antiguo?*__________ ***37. ¿Tiene refrigerador?*** *SI.....1* *¿Cuántos?*________ *NO...2* *¿Qué tiempo tiene su refrigerador más antiguo?*____ ***38. ¿Tiene Calentador de agua/boiler?*** *SI.....1* *¿Cuántos?*________ *NO...2* *¿Cuánto tiempo tiene su calentador de agua/boiler?* *Menos de 1 año............1* *De 1-5 años......2* *De 5 a 10 años.......3* *Mas de 10 años......4* *No sabe..........5* ***39. ¿Tiene licuadora?*** *SI.....1* *¿Cuántas?*________ *NO...2* *¿Cuánto tiempo tiene su*	***41. ¿Tiene lámparas de piso?*** SI........1 ¿Cuántas?_____ NO......2 *¿Cuánto tiempo tiene su lámpara de piso más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* *No sabe................5* ***42. ¿Tiene lámparas de techo?*** SI........1 ¿Cuántas?_____ NO......2 *¿Cuánto tiempo tiene su lámpara de techo más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe................5	**43. ¿Tiene máquina lavadora de ropa?** SI........1 ¿Cuántas?_____ NO......2 *¿Cuánto tiempo tiene su lavadora de ropa más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe......................5 **44. ¿Tiene máquina secadora de ropa?** SI........1 ¿Cuántas?_____ NO......2 *¿Cuánto tiempo tiene su secadora de ropa más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe......................5 **45. ¿Tiene aspiradora?** SI.........1 ¿Cuántas? NO.......2 ________ *¿Cuánto tiempo tiene su aspiradora más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe......................5 **46. ¿Tiene plancha?**	**47. ¿Tiene televisión?** SI........1 ¿Cuántas?________ NO......2 *¿Cuánto tiempo tiene su televisión más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe......................5 **48. ¿Tiene video casetera o DVD?** SI........1 ¿Cuántas?________ NO......2 *¿Cuánto tiempo tiene su video casetera o DVD más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe......................5 **49. ¿Tiene radio o estéreo?** SI........1 ¿Cuántas?________ NO......2 *¿Cuánto tiempo tiene su radio o estéreo más antiguo?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe......................5 **50. ¿Tiene computadora?** SI........1 ¿Cuántas?________ NO......2 *¿Cuánto tiempo tiene su*	**51. ¿Tiene aire acondicionado?** **SI........1 NO......2** ***¿Qué tipo de aire acondicionado tiene?*** ***Aire acondicionado en el cuarto........1*** ***¿Cuántos aparatos en total?***____ ***Sistema de aire acondicionado central.......2*** ***¿Cuánto tiempo tiene su aire acondicionado más antiguo?*** ***Menos de 1 año.........1*** ***De 1 a 5 años.............2*** ***De 5 a 10 años............3*** ***Más de 10 años..........4*** **No sabe......................5** **52. ¿Tiene ventilador?** **SI........1 ¿Cuántos?**________ **NO......2** ***¿Cuánto tiempo tiene su ventilador más antiguo?*** ***Menos de 1 año.........1*** ***De 1 a 5 años.............2*** ***De 5 a 10 años............3*** ***Más de 10 años..........4*** **No sabe......................5** **53. ¿Tiene calefacción?**____ **SI........1 NO......2** ***¿Qué tipo de aire acondicionado tiene?*** ***Calentador dehabitación..........1*** ***¿Cuántos aparatos en total?***____

COCINA/BAÑO	LUZ	LIMPIEZA	ENTRETENIMIENTO	
lavadora? Menos de 1 año...... De 1 a 5 años...... De 5 a 10 años...... Más de 10 años......4 No sabe...... 40. ¿Tiene secadora de pelo? Sí......1 ¿cuántas? ____ No......2 ¿Cuánto tiempo tiene su secadora? Menos de 1 año...... De 1 a 5 años...... De 5 a 10 años...... Más de 10 años...... No sabe......5		[illegible]	*computadora más antigua?* *Menos de 1 año..........1* *De 1 a 5 años.............2* *De 5 a 10 años...........3* *Más de 10 años..........4* No sabe......................5	

3.B Uso y Adquisición de los aparatos electrodomésticos

Ahora hablaremos de las decisiones en casa sobre las adquisiciones y uso de aparatos electrodomésticos.

54. ¿Cuáles son los electrodomésticos que han adquirido más recientemente? Por favor diga que aparato es y la fecha aproximada de compra.

____

55. ¿Los electrodomésticos que compra normalmente son? (LEER OPCIONES)

Nuevos............. 1
Usados............. 2
Tanto nuevos como usados.......... 3
No sabe................ 4

56 ¿.Dónde compra por lo general los aparatos electrodomésticos?

Tienda departamental (Como Sears, Liverpool, etc.)............ 1
Mueblería (Dico,Viana, Hermanos Vázquez, etc.).......................... 2
Supermercado (Wal-Mart, Comercial Mexicana)........................ 3
por Internet............................ 4
No sabe......................................5
Otro ______________________________ (especifique)

57. Con la siguiente escala por favor clasifique las siguientes características de acuerdo al orden de importancia que le da a la hora de comprar un nuevo aparato, en donde 4 es muy importante y 1 es nada importante. MOSTRAR TARJETA 57

	NADA IMPORTANTE	POCO IMPORTANTE	IMPORTANTE	MUY IMPORTANTE
COSTO	1	2	3	4
GARANTÍA	1	2	3	4
CONSUMO DE ENERGIA	1	2	3	4
MARCA	1	2	3	4
OTRO (especificar) ______________	1	2	3	4

57a. Suponiendo que usted pudiera comprar un electrodoméstico grande (por ejemplo una estufa o un refrigerador) para sustituir el actual que le

durará 20 años y le costará 2000 pesos. Si este aparato le ahorrarse 25 pesos al mes en el recibo de luz, usted lo compraría?
SI........... 1 (PASAR A LA SECCIÓN CUATRO)
NO......... 2 (CONTINUAR)

57b. ¿De cuánto tendría que ser el ahorro mensual para que usted comprara este electrodoméstico?
50 pesos............... 1
100 pesos............. 2
150 pesos............. 3
200 pesos............. 4
250 pesos............. 5
300 pesos............. 6
Más de 300 pesos........... 7
No compraría un nuevo electrodoméstico para reducir mi recibo de luz.............. 8
No sabe.................... 9

Ahora pasamos a la cuarta sección

SECCIÓN 4: COMBUSTIBLES EN EL HOGAR

Ahora vamos a hablar de los tipos de combustible que se utilizan en su casa.

4.A OPCIONES DE COMBUSTIBLES

Las siguientes preguntas se refieren a actividades que se llevan a cabo en su casa que pueden usar diversos tipos de combustibles: cocinar, calentar el agua, luz, secado de ropa y calefacción. No estamos tornando en cuenta actividades que solo usan electricidad.

Cocina

58. ¿Qué combustible usa para cocinar?
Madera/Carbón.............. 1
GAS LP.......................... 2
GN................................. 3
Electricidad...................... 4
Solar.............................. 5
Otro 6
Ninguna...........................7

59. ¿Dónde cocina por lo general?
Dentro de la casa........... 1
Afuera de la casa........... 2

60.Comparte los aparatos de cocina con otras casas?
Si............ 1
No.......... 2

61. ¿Los aparatos de cocina son.....
Suyos, y otros residentes del edificio los usan.............. 1
Suyos, y los usan otros vecinos que no viven en su edificio......... 2
Son del edificio.............. 3
Son de la comunidad................ 4
Negocio Propio............... 5
Otro..........................6 (especifique)__________________

APLICAR UNICAMENTE A LOS QUE SELECCIONARON GAS LP EN PREG. 58

61a. ¿Qué tipo de tanque tiene?
ilindro.............. 1
Estacionario......... 2
Ambos..................... 3

No sabe................ 4

61b1. ¿De qué tamaño es su tanque de GAS LP?

Cilindro:
20 kg........... 1
40 kg............ 2
60 kg............ 3
Otro________________
especifique)
No se............4

Estacionario:
<300 kg.......... 5
300-500 kg...... 6
>500 kg........... 7
Otro________________
(especifique)
No se.................. 8

61b2. Si no sabe PREGUNTAR: ¿Recuerda cuánto pagó la última vez que compró o llenó el tanque? ______________

61c.Aproximadamente, ¿Cuántos años tiene(n) el (los) tanque(s) de Gas LP?1
1 año........... 1
De 2 a 5 años............ 2
De 6 a 10 años.......... 3
Más de 10 años........... 4
No sabe................ 5

61d. ¿Cuántos tanques de Gas LP tiene en su casa, incluyendo los que usa y los extras? ____________________________

61e. ¿Cuándo se vacían los tanques de gas LP, como se cambian?
Se reemplazan................ 1
Se rellenan...................... 2

61f. ¿Qué tan seguido se cambian los tanques de Gas LP?

____

61g. ¿Cuánto le cuesta cada vez que cambia un tanque de Gas LP?

____

A LOS QUE RESPONDIERON EN PREG. 61a QUE TIENEN TANQUE DE CILINDRO PREGUNTAR:

61h. ¿Cómo llegan los nuevos tanques?
Por reparto............... 1
Los recoge algún miembro de la casa............... 2

PARA TODOS

62. Llega a oler fugas de su tanque de Gas LP o de su estufa?

SI........... 1
NO......... 2

63. ¿Cómo se prende su estufa?
Con pilotos.................. 1 ¿Cuántos? ________________
Con chispa eléctrica.............. **2**

64. ¿Su estufa tiene tanto quemadores como horno?
SI............... **1** ¿Cuántos? ________________
NO............. **2**

Agua Caliente

65. ¿Qué tipo de combustible usa para calentar el agua?
Madera/carbón..........1
Gas LP..................... 2
GN...........................3
Electricidad.............. 4
Solar........................ 5
Otro ....6(especifique) ________________
Ninguna....................7 **(PASAR A PREG. *69)***

66. ¿ Usted calienta el agua? (LEER OPCIONES)
Dentro de la casa.............. 1 **(CONTINUAR)**
Fuera de la casa................ 2 **(PASAR A PREG. 68c)**

67. ¿En dónde la calienta?
Calentador/boiler................ 1 **(PASAR A PREG. 68b)**
Otros medios, como calentar agua en la estufa............. 2 **(CONTINUAR)**

68a. ¿Comparte el equipo para calentar agua con otras casas?
SI..............1 **(CONTINUAR)**
NO............2 **(PASAR A PREG. 69)**

68b. ¿Cuál es la situación?
Son suyas y las usan otros residentes de este edificio........... 1
Son suyas y las usan otros vecinos que no viven en este edificio...... 2
Son del edificio 3
Son de la comunidad.............. 4
Negocio Propio.................. 5
Otro..........................6 ________________________________

APLICAR A LOS QUE CONTESTARON EN PREG.65 QUE USAN GAS LP PARA CALENTAR EL AGUA.

68c. ¿Llega a oler fugas de gas de su calentador?
SI............ 1
NO.......... 2

PARA TODOS

Iluminación

69. ¿ Qué combustible usa para iluminación?
Madera/carbon............ 1
Gas LP........................ 2
GN............................... 3
Electricidad.................. 4
Solar............................ 5
Otro ______________________________ (especifique)
Ninguna...................... 6

Secado de Ropa

70. ¿Qué combustible usa para secar la ropa?
Madera/carbon........... 1
Gas LP...................... 2
GN............................ 3
Electricidad............... 4
Solar......................... 5
Otro ______________________________ (especifique)
Ninguna.............. 6 **(PASAR A PREG.73)**

71. ¿Dónde seca la ropa?
Dentro de la casa............. 1
Fuera de la casa............... 2

72a. ¿Comparte el equipo con el que seca la ropa con otras casas?
SI........... 1 **(CONTINUAR)**
NO..........2 **(PASAR A PREG. 73)**

72b. ¿Cuál es la situación?
Son suyas y las usan otros residentes de este edificio........... 1
Son suyas y las usan otros vecinos que no viven en este edificio........ 2
Son del edificio.............. 3
Son de la comunidad...........4
Negocio Propio................. 5
Otro................................6 (especifique) __________________

Calefacción

73. ¿Qué combustible usa para la calefacción?
Madera/carbon........... .1
Gas LP...................... .2
GN..............................3
Electricidad................. 4
Solar........................... 5
Otro............................ 6 (Especifique) ___________________
Ninguna..................... 7 **(PASAR A PREG. 75A)**

74A. ¿COMPARTE EL EQUIPO DE CALEFACCIÓN CON OTRAS CASAS?
SI.......... 1 (CONTINUAR)
NO........ 2 (PASAR A PREG. 75A)

74b ¿Cuál es la situación?
Son suyas y las usan otros residentes de este edificio............ 1
Son suyas y las usan otros vecinos que no viven en este edificio....... 2
Son del edificio 3
Son de la comunidad............ 4
Negocio propio................ 5
Otro......................6 (Especificar)_________________

4.B GASTOS EN COMBUSTIBLES

Ahora vamos a hablar de las cantidades que gasta en combustibles del hogar. Si cree que le ayudará tener a la mano sus recibos, por favor hágalo.

Madera

75A. Usa madera como combustible para cualquier fin en su casa?
SI............. 1 **(CONTINUAR)**
NO............ 2 **(PASAR A PREG. 76a)**

75b.¿Con qué frecuencia paga la madera?
Mensual............. 1
Trimestral 2
Otro ....3 (especifique)___________________
No sabe..............4

75c.En promedio, cuánto paga por la madera (en cada recibo)?
Menos de100 pesos...........1
De 100 a 199 pesos........... 2
De 200 a 299 pesos........... 3
De 300 a 399 pesos........... 4
De 400 a 499 pesos........... 5

Más de 500 pesos.............. 6
No sabe............................... 7

75d. ¿Cuál es el nombre de la compañía que le provee de madera?

____

Gas LP

76a. Usa Gas LP como combustible para cualquier fin en su casa?
SI............ 1 **(CONTINUAR)**
NO........... 2 **(PASAR A PREG. 78a)**

76b. ¿Con qué frecuencia paga el Gas LP?
Mensual................1
Trimestral 2
Otro.......................3 (especifique) _______________
No sabe............... 4

76c. En promedio, cuánto paga por el Gas LP (en cada recibo)?
Menos de 100 pesos............... 1
De 100 a 199 pesos................. 2
De 200 a 299 pesos................ 3
De 300 a 399 pesos................ 4
De 400 a 499 pesos................ 5
Más de 500 pesos................... 6
No sabe.................................... 7

76d.Que compañía le provee el Gas LP? ____________________________

SI EL ENTREVISTADO NO VIVE EN CASA UNIFAMILIAR PREGUNTE:

77e. ¿Cómo se divide el recibo de Gas LP? (E*sta pregunta no aplica para casas individuales*)
En base al uso de cada casa............. 1
Como una fracción del uso del edificio completo............. 2

Gas Natural

78a. Usa Gas Natural como combustible para cualquier fin en su casa?
SI............... 1 **(CONTINUAR)**
NO............. 2 **(PASAR A PREG. 79A)**

78b. ¿Con qué frecuencia paga el Gas Natural?
Mensual................. 1
Trimestral 2
Otro..........................3 (especifique) ___________________

No sabe..................4

78c. En promedio, ¿Cuánto paga por el Gas Natural (en cada recibo)?
Menos de 100 pesos.............. 1
De 100 a 199 pesos................ 2
De 200 a 299 pesos................ 3
De 300 a 399 pesos................ 4
De 400 a 499 pesos................ 5
Más de 500 pesos.................. 6
No sabe................................... 7

78d. ¿Qué compañía le provee el Gas Natural? ______________________

Electricidad

a. Usa Electricidad como combustible para cualquier fin en su casa?
SI .... 1 **(CONTINUAR)**
NO........... 2 **(PASAR A PREG. 80a)**

b ¿Con qué frecuencia paga la Electricidad?
Mensual............... 1
Bimestral.............2
trimestral 3
Otro.......................4 (especifique) ______________
No sabe................5

79c. En promedio ¿Cuánto paga por la Electricidad (en cada recibo)?
Menos de 100 pesos.............. 1
De 100 a 199 pesos................ 2
De 200 a 299 pesos................ 3
De 300 a 399 pesos................ 4
De 400 a 499 pesos................ 5
Más de 500 pesos.................. 6
No sabe................................... 7

79d.Que compañía le provee de electricidad ? ______________________

4.C USO DE COMBUSTIBLES

as siguientes preguntas se refieren a la cantidad de combustibles que utiliza actualmente en su casa.

Madera

80a.En promedio, ¿el uso de madera en su casa es distinto hoy que hace cinco años?

SI............ 1 **(CONTINUAR)**
NO.......... 2 **(PASAR A PREG. 81a)**

80b. ¿Cómo ha cambiado el uso de madera en los últimos cinco años?
Se usa más hoy que hace cinco años........... 1
Se usa menos que hace cinco años............ 2

80c. ¿Por que razón ha cambiado? (PREGUNTE CADA UNA)
Cambios en el tamaño de la casa............ 1
Cambio a otros combustibles................... 2
Cambios en los aparatos electrodomésticos............. 3
Cambios en la calidad del combustible 4
Ajustes al uso de combustible 5
Otro.............................6 (especifique) ____________________
No se porque ha cambiado el uso de madera en nuestra casa..... 6

Gas LP

81a. En promedio, el uso de Gas LP en su casa es distinto hoy que hace cinco años?
SI............ 1 **(CONTINUAR)**
NO.......... 2 **(PASAR A PREG. 82A)**

81b. ¿Cómo ha cambiado el uso de gas LP en los últimos cinco años?
se usa más hoy que hace cinco años.............. 1
Se usa menos que hace cinco años................ 2

81c. ¿Por qué razón ha cambiado? (PREGUNTE CADA UNA)
Cambios en el tamaño de la casa................ 1
Cambio a otros combustibles....................... 2
Cambios en los aparatos electrodomésticos...... 3
Cambios en la calidad del combustible 4
Ajustes al uso de combustible 5
Otro ________________________ (especifique)
No se porque ha cambiado el uso Gas LP en nuestra casa......... 6

Gas Natural

82a. En promedio, el uso de Gas Natural en su casa es distinto hoy que hace cinco años?
Si............ 1
No............ 2 **(PASAR A PREG. 84ª)**

82b. ¿Cómo ha cambiado el uso de gas natural en los últimos cinco años?
se usa más hoy que hace cinco años................. 1
se usa menos que hace cinco años.............. 2

82c. Por que razón ha cambiado? (PREGUNTE CADA UNA)
Cambios en el tamaño de la casa................ 1
Cambio a otros combustibles................... 2
Cambios en los aparatos electrodomésticos.............. 3
Cambios en la calidad del combustible 4
Ajustes al uso de combustible 5
Otro ______________________ (especifique)
No se porque ha cambiado el uso Gas Natural en nuestra casa....... 6

Electricidad

83a. En promedio, ¿el uso de Electricidad en su casa es distinto hoy que hace cinco años?
Si............ 1
No........... 2 **(PASAR A PREG. 84ª)**

83b. ¿Cómo ha cambiado el uso de electricidad en los últimos cinco años?
Se usa más hoy que hace cinco años.......... 1
Se usa menos que hace cinco años........... 2

83c.¿Por que razón ha cambiado? (PREGUNTE CADA UNA)
Cambios en el tamaño de la casa.............. 1
Cambio a otros combustibles..................... 2
Cambios en los aparatos electrodomésticos............ 3
Cambios en la calidad del combustible 4
Ajustes al uso de combustible 5
Otro ______________________ (especifique)
No se porque ha cambiado el uso Electricidad en nuestra casa......... 6

Ahora vamos a hablar sobre los gastos que usted hace en todos los combustibles en su casa.

84a. ¿Si los precios de los combustibles aumentaran en un 5%, usted trataría de reducir el uso con el fin de reducir los cargos de combustibles?
SI............ 1 **(PASAR A PREG. 85)**
NO........... 2 **(CONTINUAR)**

84b. ¿Qué porcentaje en el aumento del precio de los combustibles haría que usted redujera su uso.?
10 %........... 1
20 %........... 2
30 %........... 3
40 %........... 4
60%........ 5
No trataría de reducir el uso de combustibles por el precio de los mismos.......... 6

No sabe........... 7

85. Si usted quisiera, ¿Cómo cambiaría su consumo de combustibles?

Comprando mas aparatos que consuman menos energía (mas eficientes)........ 1
Reducir el tiempo en que los aparatos electrodomésticos se usan............ 2
Reparando los aparatos electrodomésticos........... 4
Otro................................5 (especifique) ______________________
No se como cambiaría mi consumo de combustibles........... 5

4.D PREFERENCIAS DE COMBUSTIBLES

as siguientes preguntas se refiere a sus percepciones sobre la oferta de combustibles en la Ciudad de México.

86. Independientemente si usted usa ese combustible o no, por favor díganos su opinión sobre cada uno, de acuerdo a la siguiente escala general:
MOSTRAR TARJETA 5
1 – Malo
2 – Abajo del promedio   Regular
3 – Promedio   Bueno
4 – Arriba del Promedio   Muy Bueno
5 – Excelente

Combustible	Evaluación
Madera	
Gas LP	
Gas Natural	
Electricidad	

87. ¿Cuál es su opinión sobre la disponibilidad en el Mercado de los siguientes combustibles? MOSTRAR TARJETA 87
Escala: 1 – No disponible; 5 – Fácilmente disponible

Madera	1	5
Gas LP	1	5
Gas Natural	1	5
Electricidad	1	5

88. ¿Cuál es su opinión sobre la confiabilidad del suministro de los siguientes combustibles? MOSTRAR TARJETA 88
Escala: 1 – No confiable; 5 – Muy confiable

Madera	1	5
Gas LP	1	5
Gas Natural	1	5
Electricidad	1	5

89. ¿Cuál es su opinión sobre los precios de los siguientes combustibles? MOSTRAR TARJETA 89

Escala: 1 – Muy caro; 5 – Muy barato

Madera	1	5
Gas LP	1	5
Gas Natural	1	5
Electricidad	1	5

90. ¿Cuál es su opinión sobre la seguridad de los siguientes combustibles? MOSTRAR TARJETA 90

Escala: 1 – Inseguro; 5 – Seguro

Madera	1	5
Gas LP	1	5
Gas Natural	1	5
Electricidad	1	5

91. ¿Cuál es su opinión sobre el potencial contaminante de los siguientes combustibles? MOSTRAR TARJETA 10

Escala: 1 – Muy contaminante; 5 – No contaminante

Madera	1	5
Gas LP	1	5
Gas Natural	1	5
Electricidad	1	5

92. ¿Qué elementos toma en consideración a la hora de escoger un combustible? (PREGUNTE CADA UNA)

No hay alternativas.............. 1
Precio................ 2
Confiabilidad............. 3
Eficiencia................ 4
Seguridad............ 5
Conveniencia........... 6
Otro.........................7 (especifique) ________________

93a.Otros miembros de su familia, fuera de esta casa, usan el (los) mismo(s) tipo(s) de combustibles que en su casa?

SI............ 1 **(PASAR A PREG. 94a)**
NO.......... 2 **(CONTINUAR)**

93b. ¿Qué otros combustibles usan? ________________ **en lugar de**

____

94a.Sus vecinos usan el (los) mismo(s) tipo(s) de combustibles que en su casa?

SI.......... 1 **(PASAR A PREG. 95ª)**

NO.......... 2(CONTINUAR)

94b. ¿Qué otros combustibles usan? ________________ en lugar de ________________

95a. En los últimos cinco años ha hecho un cambio de combustible con el que cocina?
SI............ 1 **(CONTINUAR)**
NO........... 2 **(PASAR A PREG. 97ª)**

95b. ¿Qué combustible? De ________________ a________________

96c. ¿Por qué cambió? (PREGUNTE CADA UNA)
No hay alternativas............ 1
Precio................................ 2
Confiabilidad...................... 3
Eficiencia.......................... 4
Seguridad.......................... 5
Conveniencia..................... 6
Otro.................................. 7 (especifique) ________________________________

96d. ¿Hace cuántos años? ____________________________ año(s)

96e. ¿Cómo califica el servicio?
Excelente............ 3
Satisfactorio......... 2
Malo.............. 1

96f1. ¿Cambiaría a otro combustible para cocinar si tuviera la opción?
SI............ 1 **(CONTINUAR)**
NO........... 2 **(PASAR A PREG. 97a)**

96f2. ¿A que combustible? De ________________a ________________

96f3. ¿Qué le impide hacer este cambio? (PREGUNTE CADA UNA)
No sabe como cambiarse............... 1
El cambio es muy complicado............. 2
El combustible no esta disponible........... 3
No le alcanza para hacer el cambio............ 4
No le alcanza el reemplazo o el nuevo equipo........... 5
Otro..6 (especifique) ____________

97a.Ha cambiado de combustible para calentar el agua en los últimos cinco años?
SI............ 1 **(CONTINUAR)**
NO............ 2 **(PASAR A PREG. 97 f1)**

97b. ¿Qué combustible? De ________________ a ________________

97c. ¿Porqué cambió? (PREGUNTE CADA UNA)
No hay alternativa........ 1
Precio.......................... 2
Confiabilidad.............. 3
Eficiencia.................... 4
Seguridad................... 5
Conveniencia............. 6
Otro ....7(especifique) ________________________

97d ¿Hace cuántos años? ______________________ años

97e. ¿Cómo califica el servicio?
Excelente.......... 1
Satisfactorio......... 2
Malo.......... 3

97f1. ¿Cambiaría a otro combustible para calentar el agua si tuviera la opción?
SI........... 1 **(CONTINUAR)**
NO......... 2 **(PASAR A PREG. 98a)**

97f2. ¿Qué combustible? De ________________ a ________________

97f3. ¿Por qué cambiaría? (PREGUNTE CADA UNA)

No hay alternativas........... 1
Precio........... 2
Confiabilidad........ 3
Eficiencia........... 4
Seguridad............ 5
Conveniencia........... 6
Otro ....(especifique) ________________________

98a. Sabía usted que el Gas LP puede tener fugas cuando se instala un tanque y también de los pilotos y estufas?
SI.......... 1
NO......... 2

98b. Y que estas fugas de Gas LP pueden presentar riesgos a la salud, tales como problemas respiratorios y cáncer. Sabiendo esto, quisiera reducir estas fugas?
SI.......... 1
NO........... 2

98c1. Si por $500 pesos usted pudiera reparar sus pilotos y reducir las fugas en un 10%, lo haría?
SI.......... 1 **(PASAR A PREG. 99a)**
NO......... 2 **(CONTINUAR)**

98c2. ¿ Cuánto estaría dispuesto a pagar por reparar sus pilotos y reducir las fugas en un 10%?
400 pesos............. 1
300 pesos............. 2
200 pesos............. 3
100 pesos............. 4
No haría esta reparación para reducir las fugas........... 5
No sabe................ 6

98d. Que tipo de información le facilitaría tomar esta decisión?

____

99a.Que porcentaje de sus vecinos ha adquirido combustibles sin pagar por ellos?
Del 1 al 5%t 1
Del 6 al 10 %t.............. 2
Del 10 al 25 %t............. 3
Más del 25 %t................ 4
No sabe........................ 5
Ninguno....................... 6 **(PASAR PREG. 100)**

99b. Qué combustibles adquirieron sin pagar por ellos?

____

99c.Con que frecuencia adquieren combustible sin pagar por el?

____

100.Le presta atención a los precios de los combustibles? MOSTRAR TARJETA 100-101
Siempre............ 1
A veces............. 2
Rara vez........... 3
Nunca............... 4

101. El precio del combustible influye en como lo utiliza? TARJETA 100-101
Siempre.......... 1
A veces.......... 2
Rara vez......... 3
Nunca............. 4

102.Cuál de los siguientes cree usted que es el combustible de uso casero más caro?
Madera 1
Gas LP........... 2
Gas Natural 3
Electricidad...... 4

De las siguientes afirmaciones, por favor responda la respuesta que considere verdadera.

103. El Gas LP que compra a través de las distribuidoras de Gas LP tiene: MOSTRAR TARJETA 103-104
Impuestos.......... 1
Subsidios........... 2
Impuestos y Subsidios............ 3
Ni impuestos ni subsidios....... 4
No sabe.............. 5

104. El Gas natural que compra a través de las distribuidoras de Gas natural tiene. MOSTRAR TARJETA 103-104
Impuestos............ 1
Subsidios............. 2
Impuestos y Subsidios............. 3
Ni impuestos ni subsidios........ 4
No sabe.............. 5

105.La electricidad que compra a través de la compañía de luz tiene:
Impuestos........... 1
Subsidios............ 2
Impuestos y Subsidios.......... 3
Ni impuestos ni subsidios.......... 4
No sabe............. 5

<u>Ahora pasamos a la Quinta Sección</u>

SECCIÓN 5. SOLVENTES CASEROS

Esta sección contiene algunas preguntas relacionadas a los tipos de productos de limpieza y otros solventes que utiliza en su hogar.

106a.Cuáles de los siguientes productos se usan en su hogar? (PREGUNTE CADA UNA)
Limpiadores líquidos (excluyendo blanqueadores)............... 1 **(PASE PREG.107)**
Blanqueadores líquidos .... 2 **(PASE PREG.107)**
Pinturas............... 3 **(CONTINUAR)**
No se cual de estos productos se usan................ 4 **(PASE PREG.107)**

106b. ¿Qué tipo de pintura? (PREGUNTE CADA UNA)
Acrílica............ 1
de agua............ 2
de aceite.......... 3
Latex................ 4
No se que tipo de pinturas se usan............ 5

107a. ¿Dónde se guardan estos productos? (PREGUNTE CADA UNA)
En interiores............ 1**(CONTINUAR)**
En exteriores........... 2 **(PASAR 108)**
En interiores y en exteriores............. 3 **(PASAR 108)**
No se donde se guardan estos productos............. 4 **(PASAR 108)**

107b. Si dijo en el interior, en que cuarto(s) se guardan? (PREGUNTE CADA UNA)
Cocina........... 1
Baño.............. 2
Sala de estar.......... 3
Otro.........................4 (especifique) ______________________
No sabe donde se guardan estos productos............ 5

108.Donde tira estos productos? (marque todas las que corresponda)
En la basura............ 1
En el drenaje........... 2
En un lugar designado específicamente............. 3
Otro...........................4 (especifique)______________________
No se dónde se tiren estos productos............ 5

Ahora pasamos a la Sexta Sección

Ahora le preguntaré algunas cuestiones referente a su patio y su propiedad al aire libre.

109a. ¿Tiene patio en su propiedad?
SI.......... 1 **(CONTINUAR)**
NO......... 2 **(PASAR A SECCIÓN 7)**

109b. ¿Este patio es cuidado por:
Miembros de su hogar............ 1
Otros............ 2 (por ejemplo administradores de la propiedad) **(PASAR A SECCIÓN 7)**

109c1. ¿Qué actividades lleva a cabo en su patio? PREGUNTE CADA UNA)

Recreación............. 1 **(PASAR A SECCIÓN 7)**
Jardín..................... 2 **(PASAR A SECCIÓN 7)**
Animales................ 3 **(PASAR A SECCIÓN 7)**
Negocio.................. 4 **(PASAR A SECCIÓN 7)**
Siembra..................5 **(CONTINUAR)**
Otro.........................6 (especifique)__________________

109dc2. ¿Los productos son para?
Su familia........... 1
Para venta a terceros........... 2

109d1.Usa fertilizantes en su patio (por ejemplo, Ortho o Happy Flower)?
SI............ 1 **(CONTINUAR)**
NO........... 2

109d2. ¿Qué tan seguido? ____________________________

109e1. ¿Usa insecticidas o pesticidas en su patio (por ejemplo,Ortho o Happy Flower ?
SI........... 1
NO.......... 2

109e2 ¿Qué tan seguido? ____________________________

109f1.Usa pinturas para exteriores (para el exterior de su casa)?
SI.......... 1 **(CONTINUAR)**
NO.......... 2**(PASAR A LA SECCIÓN 7)**

109f2. ¿Qué tan seguido? ____________________________

<u>Ahora pasaremos a la séptima y última sección</u>

SECCIÓN 7 CONCIENCIA AMBIENTAL EN EL HOGAR

Ahora le haré unas preguntas sobre sus percepciones respecto al medio ambiente en la Ciudad de México y la relación entre los hogares y la contaminación del aire. Esta es la última parte del cuestionario.

110. ¿Cómo describiría la calidad del aire en su Municipio o Delegación?
Buena........... 1
Promedio...... 2
Mala............. 3

111. ¿Cómo describiría la calidad del aire en su colonia?
Buena........... 1
Promedio...... 2
Mala............. 3

112 ¿Cómo describiría la calidad del aire en su lugar de trabajo/escuela?
Buena........... 1
Promedio...... 2
Mala............. 3

113. ¿Usted cree que la quema de combustibles para cocinar, calentar el agua y otros usos caseros contribuye a la contaminación atmosférica?
Si.............. 1
En alguna medida........... 2
No............. 3
No sabe............ 4

114 ¿Usted cree que la quema de combustibles para cocinar, calentar el agua y otros usos caseros pueda provocar problemas de salud?
Si.............. 1
En alguna medida........... 2
No............. 3
No se............ 4

115.¿Qué otra cosa, considera que puede ser una fuente de contaminación o de riesgo a la salud en su casa? ______________________________

116.Tiene conocimiento de algún programa de ahorro de energía (por ejemplo: el Fideicomiso de Apoyo al Programa de Ahorro de Energía del Sector Eléctrico – FIDE, o el Programa para Mejorar la Calidad del Aire en el Valle de México – PROAIRE)?
SI.......... 1
NO......... 2

117.Qué cree que se deba hacer para mejorar la calidad del aire en su hogar? ____________________________

118.Qué otra(s) cosa(s) cree usted que se deberían de hacer para mejorar la calidad del aire en su colonia y/o en la Zona Metropolitana del Valle de México?

____

119. ¿Le gustaría recibir información sobre cómo reducir el consumo de energía en su hogar?

SI......... 1
NO.........2

Muchas Gracias por participar en esta encuesta; sus respuestas serán de mucha utilidad en nuestras investigaciones. Sabemos que su tiempo es muy valioso y reiteramos nuestro agradecimiento por su ayuda.

Household Practices to Decrease Energy Consumption and Pollutant Exposure

Homeowners should be made aware of small changes that can be implemented that could greatly improve indoor air quality. Research has shown that simple adjustments can save significant amounts of fuel loss and reduce exposure to fuel-related emissions. A few examples are shown below.

Cooking

The efficiency of cook stoves could been improved by:

- Adjusting the distance between the cook stove flame and the pot
- Using adequate covers
- Increasing pot insulation
- Using pressure cookers
- Using a range hood that is vented to the outside (even electric stoves for odor and cooking product ventilation). Studies have shown that range hood can remove combustion pollutants from 30 percent to 90 percent (DuPont, 1989)
- Ensuring that the stove is properly tuned
- Eliminating the pilot light by using a sparker or buying a stove with an electronic ignition.
- Not using the gas stove for space heating

Water Heating

The efficiency of water heaters could been improved by:

- Insulating the heater and distribution pipes
- Using electronic ignition
- Increasing burner efficiency
- Avoided loss from storage by using tankless heaters (as in apartment buildings)
- Using solar energy

Space Heaters

The efficiency of heaters could been improved by:

- Adjusting the wick
- Adjusting the air shutter
- Keeping the wick clean and unobstructed.
- Using Portable electric resistance heaters (less pollution, less fire risk, but higher operating cost and lower heat output) and vented gas space heaters instead of unvented, fuel-fired space heaters.

Clothes Dryers

The efficiency of clothes dryers could been improved by:

- Not having the exhaust directed indoors (sometimes done to save energy)

General Rules of Thumb

- Gas appliances produce the least CO_2 when showing a white or blue flame. Incomplete combustion is occurring when a red or orange flame.

- For vented appliances, try to prevent malfunctions, prevent backdraft from outdoor winds by ensuring a positive supply of outside air for all combustion appliances, install spillage detectors for combustion gases and properly inspect and clean fireplace.
- Repair cracked heat exchangers, damaged or disconnected chimneys, flues, or stovepipes, and leaks and cracks in wood stoves.
- Any combustion appliances and ventilation systems should be regularly inspected

Abbreviations/Organizations

AHAM: Association of Home Appliance Manufacturers

AMAI: Asociación Mexicana de Agencias de Investigación (Association of Marketing and Public Opinion Research Agencies)

ANFAD: Asociación Nationale de Fabricantes de Aparatos Domesticos (National Association of Appliance Producers)

CAM: Comision Ambiental Metropolitana (Metropolitan Environmental Commission)

CENCOS: Centro Nacional de Comunicacion Social (National Center of Social Communication)

CFE: Comision Federal de Electricidad (Federal Electricity Commission)

CO: Carbon Monoxide

COLD: Chronic Obstructive Lung Diseases

CONAE: Comision Nacional para el Ahorro de Energy (National Commission for Energy Conservation

CONAPO: Comision Nacional de Poblacion (National Council on Population)

CRE: Comision Reguladora de Energia (Energy Regulatory Commission)

DF: Distrito Federal (Federal District)

DSM: Demand Side Management

EIA: Environmental Impact Assessment

EIA: U.S. Energy Information Administration

EM: Estado de Mexico (State of Mexico)

ENIGH: Encuesta Nacional de Ingresos y Gastos de los Hogares (National Survey of Household Incomes and Expenses)

EPA: U.S. Environmental Protection Agency

FIDE: Fideicomiso para el Ahorro de Energia Electrica (Commission for Electricity Conservation)

GDF: Gobierno Del Distrito Federal (Federal District Government)

HAP: Hazardous Air Pollutant

IAQ: Indoor Air Quality

IIE: Instituto de Investigaciones Electricas (Institute of Electricity Investigations)

IMECA: Indice Metropolitano de la Calidad del Aire (Metropolitan Index of Air Quality)

IMP: Instituto Mexicano del Petróleo (Mexican Petroleum Institute)

INE: Instituto Nacional de Ecología (National Institute of Ecology)

INEGI: Instituto Nacional de Estadística, Geografia e Informatica (National Institute of Statistics, Geography and Information)

INSP: Instituto Nacional de Salud Pública (National Institute of Public Health)

INVI: Instituto Nacional de Vivienda (National Institute of Housing)

IPCC: Intergovernmental Panel on Climate Change of the United Nations

ISAT: Instituto de Salud, Ambiente y Trabajo (Institute of Health, Atmosphere and Work)

LDC: Less-Developed Country

LFC: Luz y Fuerza Centro

LGEEPA: Ley General del Equilibrio y la Proteccion al Ambiente (General Law of Ecological Balance and Environmental Protection)

LPG: Gas Licuade de Petroleo (Liquid Petroleum Gas)

MCMA: Mexico City Metropolitan Area

NAAQS: National Ambient Air Quality Standards

NG: Natural Gas

NMHC: Mon-Methane Hydrocarbons

NOM: Normas Oficiales Mexicanas (Official Mexican Standards)

NOx: Nitrogen Xxides

NPV: Net Present Value

PAESE: Programma de Ahorro de Energia del Sector Electrico (Program for Energy Conservation in the Electricity Sector)

PGPB: Pemex Gas y Petroquimica Basica

PEMEX: Petroleos Mexicanos

PFV: Programa Financiero de Vivienda (Financial Program of Housing)

PICCA: Programa Integral contra la Contaminación Atmosférica (Integral Program of Atmospheric Contamination)

PM: Particulate Batter

PROAIRE: Programa Para Mejorar la Calidad del Aire en el Valle de Mexico (Program to Improve Air Quality in the Valley of Mexico)

PRI: Partido Revolucionaro Institucional (Institutional Revolutionary Party)

PROFEPA: Procuraduría Federal de Protección al Ambiente (Office of the Attorney General for Environmental Protection)

RAMA: Red Automatica

RECS: Residential Energy Consumption Survey

SEMARNAT: Secretaría de Medio Ambiente, Recursos Naturales y Pesca (National Environment, Natural Resources and Fisheries Ministry)

SDUE: Secretaría de Desarrollo Urbano y Ecología (Ministry for Urban Development and Environment)

SO_2: Sulfur Dioxide

SPM: Suspended Particulate Matter

SSA: Secretaria de Salubridad y Asistencia (National Ministry of Health)

TOC: Total Organic Compounds

TSP: Total Suspended Particulates

UAM: Universidad Autonoma Metropolitana (Metropolitan University)

UNAM: Universidad Nacional Autonoma de Mexico (National University of Mexico)

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

VOC: Volatile Organic Compounds

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